Climate Resilience in Africa

The Role of Cooperation around Transboundary Waters

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CIWA

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The Cooperation in International Waters in Africa (CIWA) was established in 2011 and represents a partnership between the World Bank, its African partners, the European Commission, and the governments of Denmark, Norway, Sweden, the Netherlands, and the United Kingdom. CIWA supports riparian governments in Sub-Saharan Africa to unlock the potential for sustainable and inclusive growth, climate resilience, and poverty reduction by addressing constraints to cooperative management and development of international waters.

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Acknowledgments

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Abbreviations

3 I's	Water Resources Information Systems, Institutional Frameworks, and Infrastructure
AGRHYMET	Agrometeorological, Hydrology, Meteorology Regional Center
ANE	Administração Nacional de Estradas
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
BAU	Business as Usual
CILSS	Permanent Interstate Committee for Drought Control in the Sahel
CRIDF	Climate Resilient Infrastructure Development Facility
CRIP	Climate Resilience Investment Plan
DSS	Decision Support System
ENSO	El Niño Southern Oscillation
FDI	Foreign Direct Investment
FRM	Flood Risk Management
GCM	General Circulation Model
GD	Grand Deal
GDP	Gross Domestic Product
GIS	Geographic Information System
GWP	Global Water Partnership
HES	Hydro Electric Scheme
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
IWRM	Integrated Water Resources Management
IWRM&D	Integrated Water Resources Management and Development
JOTC	Joint Operating Technical Committee
LCBC	Lake Chad Basin Commission
LHWC	Lesotho Highlands Water Commission
LHWP	Lesotho Highlands Water Project
MAR	Mean Annual Runoff
MDG	Millennium Development Goal
NBA	Niger Basin Authority
NBI	Nile Basin Initiative
NGO	Nongovernmental Organization
NID	Niger Inner Delta
OECD	Organisation for Economic Co-operation and Development
ORASECOM	Orange-Senqu River Commission

PIDA	Program for Infrastructure Development
RBO	River Basin Organization
RCM	Regional Climate Model
SADC	Southern African Development Community
SAPP	Southern African Power Pool
SARCOF	Southern African Regional Climate Outlook Forum
SDAP	Sustainable Development Action Plan
SDG	Sustainable Development Goal
UN	United Nations
UNICEF	United Nations Children's Fund
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
WEF	World Economic Forum
WHO	World Health Organization
ZAMCOM	Zambezi Watercourse Commission
ZAMWIS	Zambezi Water Resources Information System
ZINWA	Zimbabwe National Water Authority
ZRA	Zambezi River Authority

Executive Summary

Climate change is impacting water resources in Africa. While the impacts will differ by time and place, climate change will have major impacts on water, including increased seasonal and interannual variability in rainfall, and increasing temperatures that cause greater evaporation and exacerbate water quality challenges. In addition to these underlying shifts, the continent faces growing risks of water extremes: more frequent and intense floods, and more frequent and prolonged droughts.

Economies, livelihoods, and ecosystems are each highly water dependent, and are therefore vulnerable to climate change. Economic systems (agriculture, energy, industry, municipal supply, navigation), livelihoods (smallholder cropping, fisheries, pastoralism, rural water supply, and the jobs that depend on economic growth), and ecosystems (aquatic biodiversity, water quality, environmental goods and services, catchment land quality) are all highly dependent on water. Climate change therefore threatens to disrupt each of these systems—economic, livelihoods, and ecological—on which life depends.

Building resilience to climate change requires strengthening water management systems, including information, institutions, and infrastructure. Investing in strengthening the information systems, institutions, and infrastructure—both natural and built—that enable more effective management of water resources will be at the core of building resilience, because it is these investments that will help economic, livelihood, and ecological systems to adapt and evolve into new and more sustainable states—including being better prepared for further change.

Over 90 percent of Africa's surface water is in transboundary basins and requires transboundary cooperation to manage optimally. In addition to its surface water, Africa has many transboundary aquifers, underlying over 40 percent of the continent. Some form of cooperation exists for most river basins (although much less for shared aquifers), but cooperation is inevitably complicated by a range of technical, economic, financial, political, and environmental challenges.

Options for building resilience to climate change will be considerably smaller if limited to actions undertaken by individual countries only—and run the risk of counter-productive investments when viewed at the regional scale. Regional-national coordination is needed if the full range of options for building resilience is to be considered. Experience shows that cooperative action can outweigh transaction costs, bring about efficiency gains, and change behavior of cooperating countries to be more 'future-oriented', leading to an expansion of potential resilience benefits in the longer term.

Cooperation around transboundary waters can take many forms, and will depend on the hydrological characteristics of the basin, as well as a variety of economic, environmental, political, and social factors. Cooperative action can range from sharing data to implementing joint transboundary projects. Transboundary cooperation can be usefully summarized around the three 'I's of Information, Institutions, and Infrastructure.

The case studies underlying this report show that appropriately planned transboundary cooperation can improve the resilience of economies, livelihoods, and ecosystems in Africa. Specifically, the case studies show that

1. Shared, trusted **information** enables
   - *Preparedness* through cross-border sharing of information can greatly improve prediction and help avert large losses of lives and property; and
   - Shared *planning* tools can help riparian's jointly decide ways to optimize water use, manage trade-offs, and share benefits;

2. Flexible, adaptive **institutions** enable
   - *Alignment of regional and national policies* that help countries build climate resilience through integration and interconnectivity of regional systems; and
   - *Frameworks for cooperative action* that help countries learn together and collectively manage their responses to a changing climate in a flexible and adaptive manner;
3. Shared approaches to **infrastructure** enable
   - *More cost-effective, efficient, sustainable, and climate-robust investments* in both natural (for example, watershed management, and reforestation) and built (for example, multipurpose dams) infrastructure. Since infrastructure represents both a major cost, and sometimes a major ecosystem risk, the potential benefits of a joint approach can be considerable; and
   - Resource and capacity stretched countries to *pool together* technical capacity, mobilize financial resources, and *adopt* increased transparency to facilitate improved design, operation, and restoration of built and natural infrastructure.

Climate change is only one of many important challenges facing water resource management in Africa, and approaches to building resilience to climate change therefore need to be embedded in broader approaches to water resource development and management. Whether desertification or floods are caused by global climate change or local factors is not important to the local people being impacted. To succeed, resilience-focused investments in information, institutions, and infrastructure need to be part of a broader integrated approach to water resource management, and investments must be made in the capacities of systems to address not only today's problems but also to adapt to tomorrow's.

Since transboundary cooperation is complex, and investments may often have a 'public good' characteristic, there is a strong likelihood of underinvestment in climate adaptation measures requiring transboundary cooperation—and significant risks of actions that may prove counterproductive at the regional scale. This report provides a conceptual framework for understanding the importance of transboundary waters cooperation for climate adaptation in Africa. It also presents examples of where transboundary cooperation is already resulting in improved resilience. In short, the report suggests that strengthening climate resilience through transboundary water cooperation is both critical and possible, but requires additional political and financial commitment to achieve. This report is one step on the pathway of generating additional political and financial commitments.

Climate finance donors and institutions have an opportunity to help address the 'market failure' that limits the supply of regional public goods, and to include support to transboundary waters as part of their support to climate adaptation in Africa. For its part, CIWA—the Cooperation in International Waters in Africa program—is committed to increasing its support to transboundary water cooperation in Africa in line with the continent's development aspirations, the global Sustainable Development Goals (SDGs), and as a critical element in helping Africa adapt to the challenges of climate change.

Purpose of this study. This report aims to draw attention to the critical role of transboundary water cooperation for adapting to climate change in Africa. The report is intended to provide a conceptual framework for understanding the links between climate change, socioeconomic development, water resources, and transboundary cooperation in Africa, as well as some examples of successful practices to date. In doing so, this report aims to help:

1. clients and technical teams strengthen their approaches to climate adaptation;
2. clients, donors, and partners mobilize resources to support transboundary cooperation for climate adaptation;
3. climate finance institutions address transboundary waters as part of their financing strategies.

1 Introduction

Water is vital to all major productive and livelihood sectors in Africa. The continent's tremendous water resources have the potential to fuel significant economic growth, secure livelihoods, and alleviate poverty. However, economic growth and poverty alleviation spur increased water demand for all areas of development, from agriculture, energy, sanitation, and human and environmental health (World Bank 2016b).

Water resources and the climate are fundamentally linked. Changes in climate, whether resulting from natural climate variations or anthropogenic climate change, alter the quantity, timing, and quality of water available across Africa. Climate change is already affecting water resources in Africa in five major ways: (a) increasing aridity; (b) more frequent and intense floods; (c) more frequent and intense droughts; (d) increasing seasonal and interannual variability; and (e) increased temperature (Chapter 2). The various regions, subregions, basins, and sub-basins across Africa are experiencing these impacts differently depending on the specific climate shifts and pre-existing conditions in the area.

Climate impacts on the water cycle are passed through to the sectors and systems that rely on water resources. Among others, agriculture, biodiversity, fisheries, forestry, hydropower, industry, and navigation are all vulnerable to climate impacts on water in unique and intertwined ways. These sectors and systems can be grouped into *three major, interconnected systems—economic systems, rural livelihood systems, and ecosystems—where vulnerabilities have important linkages with poverty reduction, economic growth, and reducing fragility*. For example, rain-fed agriculture is a key element of rural livelihood systems in Africa as it contributes almost one-quarter of the gross domestic product (GDP) and employs nearly 70 percent of the population in Sub-Saharan Africa. Changing rainfall may change the local ecosystem, undermine the livelihood of local people, and impact the economy more broadly through reducing food security, increased migration, and so on.

Without increasing resilience, climate impacts are likely to reduce food security, reverse poverty alleviation gains, and slow economic growth in many places in Africa. Increased resilience will enable people living in poverty to respond more effectively to change and to recover faster from disasters; increased resilience will also allow economic and natural infrastructure to function and thrive despite climate-change-induced shocks and stresses (Water Research Commission 2009).

To address and overcome the vulnerabilities of the many affected sectors and systems, water must be managed and developed according to the principles of sustainable water resources management and development. *Fit-for-purpose water management institutions, information systems, and infrastructure (the 3 I's) are needed for resilience of economies, livelihoods, and ecosystems*. As countries and water managers take on the challenge of putting the 3 I's in place, they must explicitly account for a changing and uncertain future climate, or they risk maladaptation and negative consequences.

Over 90 percent of Africa's surface water falls within 63 transboundary river and lake basins, while transboundary aquifers lie beneath over 40 percent of the continent. Water management measures identified only at the local and national level do not account for hydrological reality, reducing their effectiveness for achieving development goals and building resilience.

Acting at the national level limits the scope of resilience that countries can build through water management systems. Transboundary cooperation is required if countries and communities across Africa are to benefit from the full range of resilience options that they have. For example, Mozambique, a country with its major industries and numerous settlements located in a flood plain, is vulnerable to increased flooding anticipated with climate change. A flood early warning system must be implemented at the sub-basin level to warn businesses and people of their increased risk of flood damage and motivate appropriate action. Since Mozambique is downstream of several other countries, a flood warning system that focuses only on the stretch of the river within Mozambique will significantly reduce both the accuracy and the timeliness of data available: a transboundary flood warning system, if not a transboundary flood management system, is required.

The respective roles of regional, national, and local action will vary by geography, hydrology, non-structural drivers, and development need. However, *planning and design-oriented actions that account for the transboundary nature of water resources across Africa are needed to ensure that the full range of resilience options are possible*. Typically, investments of transboundary significance have a long-term time horizon (a 30- to 50-year lifetime) and climate change increases the uncertainty of future needs as well as future water availability. The potential for sub-optimal decision making without cooperation is high. However, there are many barriers to transboundary cooperation, typically motivated by riparian perception of risk and inadequate evidence or understanding of opportunities of cooperation (Subramanian, Brown, and Wolf 2012). *Limited availability of financing to address the additional transaction costs of regional approaches to climate resilience is often cited as a major barrier to transboundary cooperation in Africa.* For example, at the time of this report's publication, the Green Climate Fund has not seriously entertained financing of regional programs that improve resilience through improved coordinated basin or sub-basin level water resource management action despite recognizing the critical link between water resources and climate resilience.

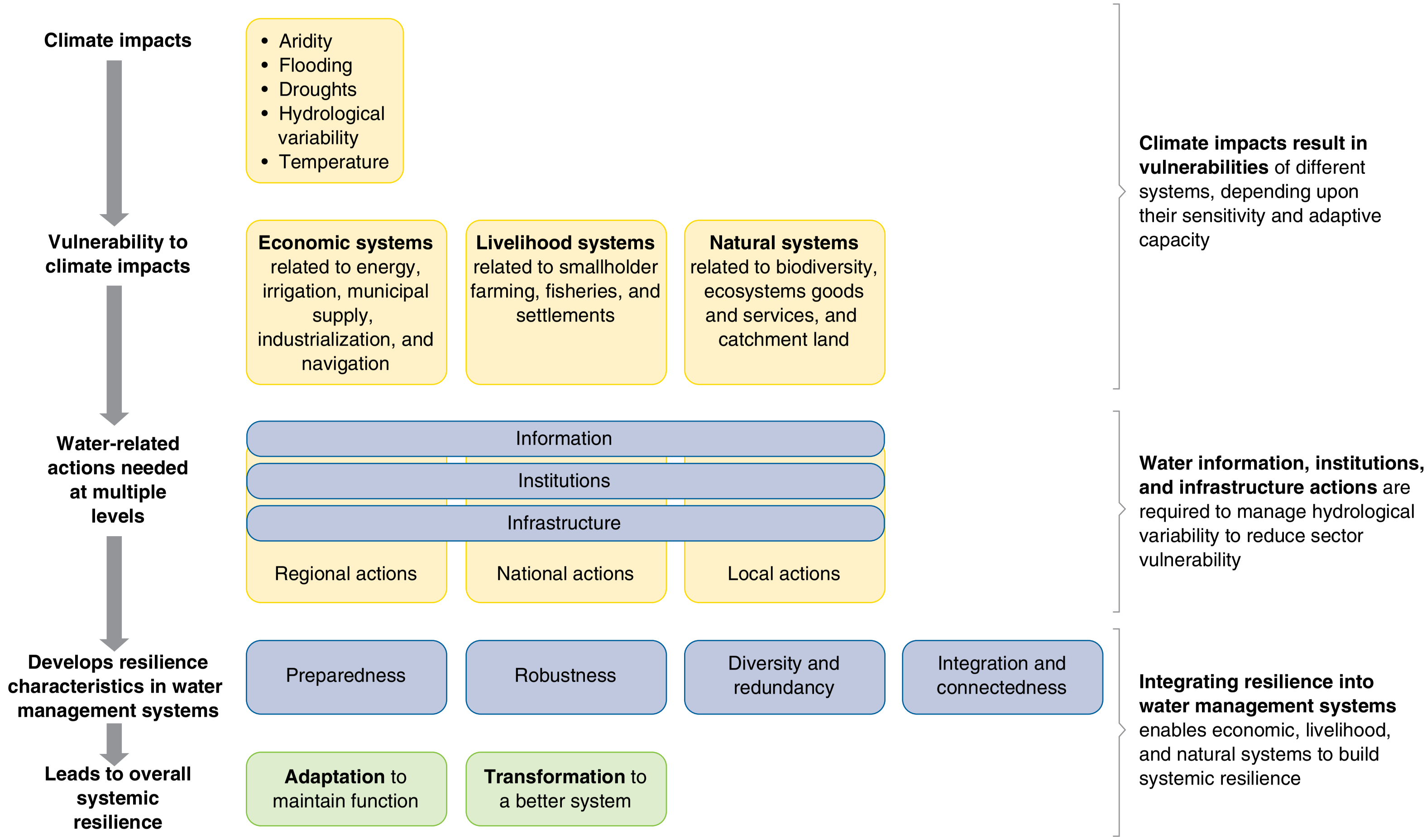
This report establishes a framework—see Figure 1—for exploring the range of issues involved in strengthening climate resilience at the transboundary, national, and local levels. To do this, the report draws together literature from the climate adaptation and resilience community, the principles of integrated water resources management (IWRM), and the literature that describes opportunities and barriers to transboundary cooperation. Examples from African basins where transboundary cooperation complements national action to deliver specific resilience outcomes illustrates the issue and substantiates the hypothesis that resilience would be fundamentally limited by unilateral action only. The report also highlights the risk of maladaptation or negative consequences of managing shared water resources without transboundary cooperation.

The study is divided into six sections: (a) the impacts of climate change on water resources across Africa; (b) the vulnerabilities of economic, livelihood, and ecological systems to these impacts, along with the actions needed to reduce those vulnerabilities; (c) how water-related resilience actions are needed at the local, national, and transboundary levels, despite associated challenges and costs; (d) the role of transboundary cooperation in enabling sustainable and robust investments and infrastructure, shared and trusted information, and flexible adaptive institutions; (e) the benefits of such cooperation beyond the water sector; and (f) recommendations for how to operationalize transboundary water management to build climate resilience.

BOX 1 Global risks to economies and societies are closely linked to water resources and increased by climate change

When asked about the expected risks considered to be the most concerning to economies and societies for the next 10 years, global leaders named four water-related risks, directly caused by or strongly intertwined with climate factors: (a) water crisis, (b) failure of climate change adaptation and mitigation, (c) extreme weather events, and (d) food crisis (World Economic Forum 2016). This speaks volumes about the importance of building water-related resilience to climate variability and change.

FIGURE 1 Report framework: Multiple types and levels of water-related action are needed to build resilience to climate change in Africa



2 Building Water-Related Resilience to Climate Variability and Change

KEY MESSAGES

- Despite differences in climate model projections and associated uncertainties, it is broadly agreed that climate change will impact temperature and precipitation, thereby impacting Africa's hydrological regimes. Different parts of the continent will be exposed to different climate impacts, which can broadly be characterized as increasing aridity, more frequent and intense floods, more frequent and prolonged floods, increasing seasonal and interannual variability, and increasing temperatures that cause greater evaporation and introduce water quality challenges.
- In Africa, economic systems (energy, agriculture, industry, municipal supply, navigation), livelihoods (smallholder cropping, fisheries, pastoralism, rural water supply), and ecosystems (aquatic biodiversity, ecosystem goods and services, catchment land quality) are highly dependent on water, and are therefore vulnerable to climate impacts (summarized in Table 1).
- Through a combination of improved information systems, institutional frameworks, and infrastructure (the 3 I's), water management systems provide opportunities for reducing vulnerabilities of the economy, livelihoods, and ecosystems to impacts of climate change.
- Increased resilience in economic systems, livelihoods, and ecosystems is reflected through the strengthening of four characteristics—preparedness, diversity or redundancy, integration or connectedness, and robustness—in their water management systems, which enable them to absorb current and future climate-related shocks and stresses and maintain function in the face of it.
- Interaction of these four characteristics of resilience in water management systems enables economic systems, livelihoods, and ecosystems to further develop the two following capabilities characterizing systemic resilience, which enable the systems to adapt, reorganize, and evolve into new sustainable states that are more suited to a changing climate and are better prepared for further changes: adaptability of a system to change and transformability of a current system to a better system.

The impacts of climate change will be primarily channeled through the hydrological cycle, and Africa will be particularly hard-hit (World Bank 2016b). The temperature will increase, and other changes will manifest themselves differently across the continent, but in general there will be an increase in aridity, an increase in floods and droughts, and an overall increase in hydrological variability, causing more intense rainfall and shifting annual rainfall patterns (see Section 2.1).

Because African economies, societies, and ecosystems depend on water resources, they are vulnerable to the impacts of climate change (Section 2.2). Strengthening water management systems is needed to reduce these vulnerabilities and build resilience (Section 2.3). However, Africa's water resources are nearly all shared by more than one country and require transboundary cooperation as well as national action to put the appropriate water management systems in place (Section 2.4).

2.1 Climate Change Impacts on Water Resources in Africa

Understanding the impacts of climate change is complex and subject to uncertainty. The uncertainty in climate science arises from difficulties of modelling the complex and interrelated physical systems that drive climate,[1] lack of data (incomplete knowledge on natural variability), underdeveloped understanding of the dynamic relationship

1 The limitations of climate models generate a wide range of projections that vary in both the direction and magnitude of changes in precipitation. This uncertainty is heightened when model results are downscaled (Miralles-Wilhelm 2017).

between different earth systems (such as the interaction between atmospheric carbon and oceans), unknown future greenhouse gas concentrations, and several 'unknown unknowns'. The Intergovernmental Panel on Climate Change (IPCC) recognizes that assessment across numerous models and varied scenarios is required.

Despite the complexities, there is increasing convergence in some climate projections for Africa. The IPCC's fifth assessment report shows that Africa's climate is already changing, impacts are already being felt, and that further climate change is inevitable in the next few decades. Climate change is strongly expected to increase climate variability in Sub-Saharan Africa (Euroconsult Mott MacDonald 2008). Climate change is also expected to cause changes in average temperature and precipitation regimes.

Subsequently, these changes will translate into impacts on water resources. The following five impacts of climate change on water resources are identified as the primary impacts in Africa through which key vulnerabilities of economies, societies, and ecosystems will be felt:

- A trend toward aridity
- More frequent and intense floods
- More frequent and intense drought
- Increasing seasonal and interannual variability
- Increasing temperatures

These impacts are described in Box 2, and further elaborated in Annex B.

BOX 2 Primary impacts of climate change on water resources in Africa

The effects of climate change on water resources play out in several distinct ways, all of which have implications for river basins in Africa (additional details about climate impacts are in Annex B):

Increasing Aridity

More of Africa's land will become arid due to climate change. Aridity is projected to spread due to changes in both temperature and precipitation, especially in southern Africa. If temperatures rise by 4°C this century relative to the mean annual temperature of the late twentieth century, Africa's hyper-arid and arid areas are projected to expand by 10 percent compared to the 1986–2005 period (World Bank 2013). *For water resources in Africa—including rivers—this implies drier and more denuded ecosystems, with more damaged and deteriorating catchments.*

This trend toward aridity is also explained by climate change's impact on rainfall. Under multiple emission scenarios, a reduction in precipitation is likely over northern Africa and southwestern parts of southern Africa by the end of the 21st century. There is more uncertainty about projected rainfall change over greater Sub-Saharan Africa in the mid and late 21st century. Changes in rainfall ultimately translate into changes in runoff. In the southern part of the continent, countries like South Africa and Botswana show a consistent trend toward less runoff. Certain climate models produce large decreases in runoff toward the second half of the century in the Central African Republic, the Democratic Republic of Congo, Malawi, Mozambique, Tanzania, Zambia, and Zimbabwe (Miralles-Wilhelm 2017). *Such likely decreases in runoff will compound increasing trends in aridity.*

More Frequent and Intense Floods

Climate models suggest greater variance in the magnitude of rainfall volumes, including the likelihood of more heavy rainfall events. This will increase the occurrence of floods in regions like east Africa, where such trends are clearest (IPCC 2014b). Climate change is expected to impact the frequency, duration, and intensity of floods. However, it must be noted that flood projections under climate change are still not very well understood for Africa in most river basins.

Changes in the intensity of rainfall events modify flood patterns and groundwater recharge, and changes in average annual rainfall volumes alter mean annual runoff (MAR) and system yields (Water Research Commission 2009). *The implications for water resources in Africa include increased uncertainty around both annual water availability and groundwater recharge.*

More Frequent and Prolonged Droughts

Climate change is expected to impact the frequency, duration, and intensity of droughts. Models indicate a significant trend toward moderate and severe water scarcity in north Africa by mid-century, that is, between 2025 and 2050 (Miralles-Wilhelm 2017). The IPCC notes with high confidence that climate change will exacerbate existing stress on water availability in Africa. There is medium confidence that droughts will intensify in east and southern Africa in the 21st century (IPCC 2014b). *The impacts on water resources in Africa include less surface water and less groundwater recharge, which imply lower flows in rivers during periods of drought.*

Increasing Seasonal and Interannual Variability

Climate change in Africa is expected to exacerbate existing climate variability, including by changing the onset and duration of seasons of wet and dry seasons, and altering the hydrological cycle from year to year. Changes in the onset of rain are also likely to affect the duration and timing of low and high flow periods. Existing climate variability drivers such as El Niño Southern Oscillation (ENSO) may be influenced by climate change (IPCC 2014b). *For water resources, this means greater unpredictability around availability and reduced reliability in access.*

Increased Temperature

Climate change is expected to increase mean annual temperature and extreme temperature episodes, as well as to modify seasonal temperatures (day- and/or nighttime temperature). Mean annual temperature rise over Africa is likely to exceed 2°C by the end of this century. Warming projections under moderate emissions scenarios suggest that large areas of Africa will exceed 2°C of temperature rise by the last two decades of this century; under high emissions scenarios this extends to the entire continent. Under extremely high emissions scenarios, the 2°C rise could take place even by mid-century, with the increase reaching between 3°C and 6°C by the end of this century. It is expected that land temperatures over Africa will rise faster than the global land average, particularly in the more arid regions, and that the rate of increase in minimum temperatures will exceed that of maximum temperatures (IPCC 2014b). *For water resources in Africa, the direct implications of temperature rise include higher water temperature and higher evaporation rates.*

2.2 Economies, Livelihoods, and Ecosystems Depend on Water and Are Vulnerable to Climate Impacts

The vulnerability of a system to climate impacts includes its exposure[2] to climate change and variability (external dimension), but also its sensitivity to these factors and its adaptive capacity (internal dimension) (IPCC 2008). Vulnerability represents the propensity or predisposition to be adversely affected, and so it is a characteristic that influences the magnitude of impact (IPCC 2012). This framework identifies thee major interlinked systems that experience vulnerabilities to water-related climate impacts: economic systems, rural livelihoods, and ecosystems (for an in-depth assessment of these three systems see Annex A). Evidence on how these systems are affected by subsector is drawn from five major transboundary basins in Africa: Nile, Zambezi, Limpopo, Niger, and Lake Chad Basins (snapshots of these five basins are found in Annex B).

2.2.1 Vulnerabilities of economic systems

Economic systems are vulnerable to climate change's impacts on water resources because of their inherent reliance on sufficient quality and quantity of available water. Large-scale economic systems are also vulnerable to the destructive powers of climate-related shocks such as drought, floods, and other hazards. It has been estimated that water scarcity induced by climate change could lead to 6–14 percent decline in growth rates in some regions of the

2 Exposure can also be defined as the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

world, which do not manage climate change adequately (Sadoff, Borgomeo, and de Waal 2017). Climate-related economic downturn has further consequences on the demography and stability of socioeconomic systems. For example, there have been cases where economic growth has been impaired by rainfall patterns, episodes of droughts and floods have generated waves of migration and spikes of violence (Sadoff, Borgomeo, and de Waal 2017).

In Africa, vulnerabilities of energy, agriculture, industry, municipal supply, and navigation sectors to climate-related impacts on water resources share several commonalities, but are manifested uniquely in each sector as reflected in Table 1.

TABLE 1 Climate impacts through water on economic systems

	Hydropower and Thermal Power	Irrigation	Industry	Municipal Supply	Navigation
Increased Aridity	Reduced average generation due to reduced stream flow	Increased irrigation needs and demand due to expansion of dryland surfaces, higher evapotranspiration, and higher crop water requirements	Shortages in water supply, affecting requirements for productive activities Worsened water quality by reduction of dilution effect	Shortages in water available for municipal supply, worsened water quality Increased groundwater extraction, reduced groundwater storage	Reduced navigation options due to low levels of water in rivers and lakes
More Frequent/ Intense Floods	Increased dam safety-related risks due to increased flood peak Increased reservoir sedimentation, reducing generation efficiency and reliability	Over-inundation and destruction of crops Reduced irrigation capacity due to sediment deposition in canals	Damage to industrial infrastructure Interruption of operations	Damage to municipal water supply infrastructure, deteriorated water quality, leading to interruption in supply	Damaged river banks and obstructing debris rendering rivers temporarily un-navigable
More Frequent/ Prolonged Drought	Reduced generation during drought periods	Increased needs and demand for irrigation	Interruption or suspension of activities in industries that depend on water Hampered industrial production through diminished water quality	Reduced availability for supply Deterioration in water quality	Reduced navigation options due to low levels of water in rivers and lakes
Increasing Variability (seasonal and interannual)	Reduced generation reliability and predictability, impacting electricity supply	Reduced predictability in availability of water for irrigation, challenging business and investment planning	Reduced predictability around water availability, challenging business and investment planning	Reduced predictability Deterioration in water quality	Navigation challenges due to increased sedimentation Reduced navigation predictability challenging business and investment planning
Increasing Temperature	Increased cooling requirements for thermal stations Increased evaporation reduces average generation Proliferation of invasive vegetation such as water hyacinth that blocks and damages turbines	Increased irrigation needs due to increased crop water requirements and increased evaporation in reservoir and supply systems	Increased water requirements for industrial production Possible impacts on worker health in industries such as mining Impacts on ecosystems may also reduce appeal of ecotourism and affect ranching activities	Increased demand for water in urban centers Deteriorated water quality due to increased growth of algal, microbial, invasive aquatic plants Increased risk of waterborne diseases	Increased growth rates of invasive aquatic plants

Some concrete examples collected from the literature evidence how these impacts will manifest in the major transboundary systems analyzed in this report. For example, the energy sector in the Zambezi will be affected under the driest climate change scenarios, as there will be flow reductions and higher evaporation rates. Maladaptation to climate could potentially translate into up to US$42.1 billion losses between 2015 and 2050 in hydropower revenues (Cervigni, Liden, and Neumann 2015). Another study estimates that, in a drying climate, output from major hydropower plants in the Zambezi will decline by 10–20 percent (Spalding-Fecher, Joyceb, and Win 2017). Further, meeting established hydropower needs via increased production of coal-fired power will have cost implications in the regional electricity system, and also increase greenhouse gas emissions (Spalding-Fecher, Joyceb, and Win 2017).

Similarly, the irrigation sector will also experience losses under the driest climate change scenario in the Nile or the Niger. In the absence of any adaptation, irrigation revenues could fall by US$13.2 billion in the Nile Equatorial Lakes region, US$0.8 billion in the Eastern Nile, and US$0.8 billion in the Niger region (Cervigni, Liden, and Neumann 2015).

As stated in Box 2, more intense floods and droughts have impacts on water resources, and consequently on economic systems. According to a report published by the World Bank in 2016, dry lands in the Sahel could expand up to 20 percent by 2030, affecting the agriculture sector due to chronic droughts. Meanwhile floods in the Zambezi Basin have already proved to destroy infrastructure and affect a myriad of industrial activities, generating losses of over US$1billion. In another example, in 2015, the south of Malawi and central Mozambique (along the Shire) were affected by devastating floods caused by heavy rainfalls following Cyclone Bansi, which disrupted industrial activities and resulting economic growth in the Shire Basin, but also throughout southern Africa.

2.2.2 Vulnerabilities of rural livelihoods

Water is key to livelihoods. It is crucial to people's survival, and necessary to ensure basic corporal and food hygiene. In rural contexts, water is needed for settlements and supply, as well as for subsistence activities like smallholder farming, fishing, and pastoralism. Climate change can thus affect living conditions and the viability of traditional subsistence activities as reflected in Table 2. In extreme cases, the long-term consequences of climate and hydrology changes in specific regions can make them uninhabitable, forcing populations to move.

In several African states, the vulnerability to climate-related shocks and stresses is heightened by the low levels of adaptive capacity of rural communities. Further, many African states have experienced difficulties in providing water services, protecting water resources and people from water-related disasters, and addressing water insecurity. This makes communities, especially rural ones, highly exposed to climate shocks impacting water resources. In a recently published report, Sadoff, Borgomeo, and de Waal (2017) evidenced how water security, key to reduce livelihood vulnerability, is more difficult to achieve in fragile contexts, a sociopolitical characteristic that qualifies a significant part of Africa.

Some concrete examples collected from the literature evidence how these impacts will manifest in Africa and in major transboundary systems analyzed in this report. For example, reduction of water availability as a consequence of climate change can disrupt subsistence farming by reducing crop yields. In west Africa there is a substantial risk of reduced crop yields, with an estimated 11 percent reduction by the 2080s. Further, water-related natural disasters would also affect rural communities, as has been the case in the past. Droughts are particularly harmful to rain-fed agriculture and pastoralism. In the Niger, droughts have caused famines, killing up to 250,000 people and decimated over two million livestock in the 1970–1973 period (Kandji, Verchot, and Mackensen 2006). Similarly, pastoralists in southern Ethiopia lost nearly half their cattle and roughly 40 percent of their sheep and goats to droughts in the period 1995–1997, and were limited to pursuing other farming options due to the diminished carrying capacity of the land (World Bank 2013). Floods have also had tremendous impacts in the past. In Ethiopia, the 2006 floods resulted in 700 deaths and displaced 242,000 people. In the Niger Basin, floods in 2012 destroyed hundreds of thousands of farm acres of land in Nigeria, displacing 1.3 million people and causing 431 deaths (Kandji, Verchot, and Mackensen 2006).

Extreme climate events not only impact livelihoods through the actual disaster shock, they also—for the risks they present—push poor households to adopt low-risk strategies that have low returns, and leave no prospect of rising above the poverty line (Hallegatte et al. 2016). The Zambezi Basin provides a quantitative illustration of

TABLE 2 Climate impacts through water on livelihoods

	Subsistence Farming and Pastoralism	Fisheries	Settlement and Supply
Increased Aridity	Decreased soil fertility and yields impact livelihoods of communities dependent on rain-fed agriculture May lead to internal or international migration, and increase competition with host communities	Low levels of water can impact fishing opportunities by diminishing or reducing diversity of fish populations	Loss of wooded vegetation can impact the energy security of rural villagers who depend on charcoal and fuelwood
More Frequent/ Intense Floods	Destruction of farming assets such as crops and farming infrastructure Death of cattle and livestock Pre- or post-disaster displacements (internal or international migration), and increased competition with host communities	—	Loss of life, destruction of infrastructure, property, and livelihoods Risk of food insecurity and waterborne diseases
More Frequent/ Prolonged Drought	Food insecurity and famines, can lead to loss of life and livestock Pre- or post-disaster displacements (internal or international migration), and increased competition with host communities	Decline in fishing opportunities and in fisheries outputs	Impact on levels of water supplied to rural communities Can lead to water quotas per capita
Increasing Variability (seasonal and interannual)	Affects agricultural timing including planting and harvesting	—	Affects predictability
Increasing Temperature	Declined yield Increased likelihood of pest infestation and increased crop stress	Can affect survival and diversity of fish populations, impacting outputs of fishing and fish farming	—

these strategies. In Zimbabwe for example, half of the costs relating to droughts were linked to "ante impacts from increased weather risk" (Elbers, Gunning, and Kinsey 2007). Another study has shown that extreme climate events—those that happen once every 30 years—could double the number of poor urban laborers in vulnerable countries like Zambia and Malawi (Ahmed, Diffenbaugh, and Hertel 2009). Such events of rare extreme intensity could harshly affect urban laborers, increasing poverty rates of this group to 111 percent in Malawi and 102 percent in Zambia (Ahmed, Diffenbaugh, and Hertel 2009).

The basins studied show a consistent increase in dryness and aridity. In the Niger Basin, for example, this increase is likely to result in a decrease in soil fertility and yields, impacting livelihood farming and pastoralism. Aridity can also increase pest infestations and crops stress, as is feared in the Nile Basin. In Chad, this aridity is likely to result in the movement of populations (especially subsistence farmers and cattle herders) toward greener areas, which can increase competition for land resources and tensions with host communities. The movement of population is mainly from the north to the south of the Lake Chad Basin. In the Limpopo Basin, increased dryness is expected to affect natural ecosystems such as wooded vegetation; this could impact the energy security of rural villager's dependence on charcoal and fuelwood. Moreover, in poverty-stricken areas in the Mozambican part of the Limpopo Basin, as well as drier parts of Botswana and Zimbabwe, increasing climate dryness could make access to potable water and sanitation more difficult.

BOX 3 Vulnerabilities to climate impacts are particularly stark in fragile states

In fragile and conflict-affected states, high levels of poverty, constrained resources, limited infrastructure, inadequate information, and weak institutions constrain the ability to adapt and build resilience to climate-related vulnerabilities. Appropriate macroeconomic policy, governance structures, social development features, and infrastructure that can help an economy withstand or recover from shocks and stresses are largely absent in fragile states.

In a recent report entitled *Turbulent Waters: Pursuing Water Security in Fragile Contexts,* the World Bank finds that in fragile states, where institutions and governmental structures lack capacity and legitimacy, it is especially difficult for communities to build resilience to climate-induced shocks and stresses which affect their water supply as well as their livelihoods (Sadoff, Borgomeo, and de Waal 2017). Lack of appropriate government action to tackle climate risks acts as a risk multiplier: "when institutions insufficiently and ineffectively respond to escalating risks of any kind, the ability of affected populations to cope with and build resilience to risks can be challenged" (Sadoff, Borgomeo, and de Waal 2017).

Water security, which is one key aspect of resilience, is also more difficult to achieve in fragile states. That is explained by a variety of factors, such as weak institutions and information systems, strained human and financial resources, and degraded infrastructure (Sadoff, Borgomeo, and de Waal 2017). Fragility tends to negatively impact levels of water security, and high levels of water insecurity in turn triggers social, political, and economic costs to a society. Water insecurity acts as a destabilizing force in fragile contexts, thereby fueling a vicious cycle.

Many countries or situations in Africa are fragile and are particularly vulnerable to climate change. The map below shows the high number of countries affected by fragility, conflict, and violence, and highlights the areas where vulnerability to climate impacts is particularly stark.

Source: FY18 Harmonized List of Fragile Situations, World Bank.

2.2.3 Vulnerabilities in ecosystems

An understanding of how climate change impacts natural ecosystems, including through changes in water resources, is crucial to the formulation of an economic argument for transboundary cooperation on the common water resource. It is ecosystems that produce goods and services that are beneficial to the economy and to the growth of basins' riparian states throughout Africa, and represent the foundation of productive activity in the continent.

The consequences of climate change on ecosystems are manifold, some more closely tied to water resources and others to temperature. Overall, studies suggest that Sub-Saharan African ecosystems will undergo a marked change. In terms of species richness, for instance, research indicates that in a world that is 4°C warmer (by the 2040s), 10–15 percent of species endemic to the region will face the risk of extinction.

The negative effects of climate change on ecosystems are likely to be intensified by the lack of adaptive capacities developed in fragile African contexts. Fragile states are likely to show a limited ability or willingness to protect water resources and the ecosystems depending on these, from climate-induced shocks and stresses. The vulnerability of key natural features in Africa—aquatic biodiversity, aquatic ecosystems goods and services, and catchment lands—to climate-induced shocks and stresses is important to review to get a full picture of areas where resilience can be boosted through cooperative and forward-looking interventions.

Some concrete examples collected from the literature evidence how these impacts will manifest in Africa and in major transboundary systems analyzed in this report. For example, the increasing dryness and aridity expected throughout Sub-Saharan Africa will negatively impact natural systems. In the Nile Basin, increased dryness is expected to intensify thermal stratification in equatorial lakes, which in turn would increase algal productivity and

TABLE 3 Climate impacts through water on ecosystems

	Aquatic Biodiversity	Ecosystem Goods and Services	Catchment Land Quality
Increased Aridity	Reduced flood area can reduce vegetation density impacting both flora and fauna Amplified eutrophication and reduced water quality Reduced water availability impacts inland coastal salinity, and coastal integrity, which can degrade or destroy aquatic ecosystems	Reduced water availability impacts the ability of ecosystems to provide ecosystem goods or services	Soil loss and land degradation
More Frequent/ Intense Floods	—	Reduced functionality of ecosystems services through destruction of ecosystems	Increased erosion, soil loss, and land degradation
More Frequent/ Prolonged Drought	Potential destruction of aquatic species of fauna or flora	Impact on the ability of ecosystems to provide ecosystem goods or services	Increased pressure over the catchment
Increasing Variability (seasonal and interannual)	May impact diversity of fauna and flora	—	Increased erosion, soil loss, and land degradation
Increasing Temperature	May impact diversity of fauna and flora	Risk of increased thermal stratification in lakes can lead to increased algal productivity and microbial mineralization, reduced oxygen dissolution, and negative impacts on water quality, lake biodiversity, and ecosystem services	—

microbial mineralization, and reduce oxygen dissolution, impacting water quality, lake biodiversity, and ecosystem services. In Niger, a drier climate could result in 3,000 km^2 reduction of the Niger Inner Delta (NID), which will impact aquatic biodiversity, fisheries, and rice production (Zwarts et al. 2005). In the Limpopo, reduced water availability is expected to affect inland coastal salinity, and coastal integrity. Salt water intrusion in the Lower Limpopo Basin region is expected to reach 30 km inland by 2030, over an area as large as 83 km^2 (INGC 2009). In Chad finally, aridity, coupled with industrial pollution, is expected to lead to an increased eutrophication of water resources.

Similarly, catchment areas will also be affected by climate change. For example, in the Fouta Djallon highlands, the main river catchment areas of the Niger River, climate change is expected to exacerbate the already existing pressures. The area, which is characterized by high population density, and an already degraded ecosystem due to unsustainable agricultural practices, deforestation, or uncontrolled bush fires, will experience rainfall declines causing a decrease in the vegetation density in the Fouta Djallon. Reduced vegetation cover is also expected in other areas of the Niger Basin due to aridity increase. This will cause the runoff coefficient to increase, reducing aquifer recharge rates, which could be exacerbated by a potential decrease in rainfall (UNEP 2014).

2.3 Water Management Systems Can Reduce Vulnerabilities and Build Resilience

While climate impacts and related hazards are largely exogenous, communities, governments, nongovernmental organizations (NGOs), and the private sector can take advantage of significant opportunities to reduce the sensitivity and vulnerability of the communities and the economy, by adopting strategies to adapt as well as increase systemic resilience. Adaptation is defined as "the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects" (IPCC 2014a). Adaptive measures include mitigation measures (to reduce the impact's likelihood), prevention (to reduce damage/sensitivity of the system), and preparedness and relief (to respond to the hazard's occurrence). Resilience is defined as "the capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation" (IPCC 2014a). Concretely, appropriate physical assets, social capital, economic resources, and political access can assist communities or groups to absorb shocks, overcome vulnerabilities, and increase their resilience.

Development and management of water resources can embody key adaptation strategies for communities and groups and are important to building resilience of economic systems, rural livelihoods and ecosystems. These water management systems comprise the 3 I's—shared, trusted Information systems; robust, flexible Institutions; and sustainable, resilient Infrastructure. Built and natural infrastructures provide critical capabilities for managing increasing variability and extreme events stemming from climate change. Manmade reservoirs and natural storage in lakes, wetlands, and groundwater allow water to be stored when flows are high, both to reduce floods and to ensure availability during drier periods. However, storage in and of itself is not sufficient to build resilience. Transport and delivery infrastructure, such as canals, dykes, and inter-basin transfer schemes, is essential to translate availability into reliability, both in times of scarcity and excess. Clusters of large, multipurpose infrastructure implemented from a basin perspective can provide wide-reaching water security and climate-resilience benefits by optimizing competing water development opportunities and minimizing disaster risk. Small-scale infrastructure is equally important for targeting cost-effective water supply and flood and drought mitigation solutions to the rural poor. Allocation decisions between sectors, communities, and ecosystems, as well as monitoring, enforcement, and watershed management actions are also important aspects of water management needed to reduce vulnerabilities and mitigate risks of increasing extreme events. To ensure that water is managed adequately and that infrastructure is built, operated, and maintained in a sustainable and regionally beneficial manner, it needs to be backed by robust and flexible institutions that can be adapted to changing future needs and climate scenarios, as well as information systems that enable understanding of current conditions, and as well as predicting and planning for the future (Sadoff and Muller 2009).

Well-designed, water-related infrastructure, flexible water management institutions, and shared, trusted water and climate information are the water management systems African economies, societies and ecosystems need to enable adaptation and resilience to climate change (Box 4).

BOX 4 Water management systems build resilience in economic systems, rural livelihoods, and ecosystems

Information systems that can be used to build climate resilience are:

- **Data monitoring and sharing systems** based on relevant monitoring, including hydro-met, geomorphological, economic, demographic, or institutional information.
- **Decision support systems (DSSs)** that build on acquired data and understanding, including flood and drought early warning systems, assessment tools, and hydro-economic models.

Institutional systems that are used to build climate resilience are:

- **Flexible policy and legal instruments** that govern the management and development of water resources that enable responses to changing conditions.
- **Institutionally and financially sustainable organizations** involved in the management and development of water resources that enable learning and adaptation to change.

Infrastructure systems that enable climate resilience are:

- **Basin-scale, resilience-targeted investment planning** that identifies a portfolio of projects that together builds systemic resilience and does not foreclose future development options.
- **Robust infrastructure investment implementation** through appropriate preparation, development, operation, and restoration of built and ecological infrastructure.

As depicted in Table 4, water management systems can be thought to build resilience at two different levels. First, resilience derived directly from water management systems, or the capacity to recover from shock, stress, or change, can be unpacked using four primary, descriptive characteristics: preparedness, diversity and redundancy, integration and connectedness, and robustness. These four characteristics describe planning and design-oriented action that countries and communities undertake to reduce vulnerabilities of economic systems, livelihoods, and ecosystems. Beyond that, combining these four characteristics of water management systems enables systemic resilience which is built on broader development outcomes that go beyond the water sector. As described in Table 4, systemic resilience is characterized by adaptability of a system to change and transformability of a system to a better system. Systemic resilience enables shifts in social or economic activities or behaviors that are needed to respond to the pressures of significant changes in climate. Altogether, these six characteristics enable resilience to natural and increasing variability, as well as future adaptation to unknown changes. Resilience in water management systems is further unpacked in Chapter 3 and the contribution of resilience built through water management systems to enhanced, systemic resilience is described in Chapter 4. Annex C contains an expanded definition of these characteristics as relevant to water management systems.

This distinction builds on the adaptation pathways approach in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (AR5) (IPCC 2014a), in which a distinction is made between incremental adaptation and transformational adaptation. Transformation is defined as "a change in the fundamental attributes of natural and human systems," which may reflect systemic impacts of climate change. However, in AR5, it is also recognized that "restricting adaptation responses to incremental changes to existing systems and structures, without considering transformational change, may increase costs and losses and miss opportunities." These transformations reflect strengthened, altered, or aligned paradigms in the economic, social, technical, or political spheres. In this report, this concept of transformability is extended to include the ability of these systems to fundamentally transform themselves, as a key aspect of systemic resilience.

TABLE 4 **Water management systems build resilience**

Characteristics of Resilience		Water Management Systems That Build Resilience
Characteristics of Resilience in Water Management Systems	**Preparedness** to manage and cope with change and shocks	Flood forecasting, early warning systems, emergency response plans, flood protection plans, urban planning and development, storage, system operating rules, land-use management, watershed management, preservation of natural infrastructure
	Diversity and redundancy to ensure continuation of functionality	Linked water systems and regional power pools operated at different assurance, diversity in water and energy supply sources, diversity in crops and irrigations practices relevant to climate systems, excess institutional capacity, shared information systems
	Integration or connectedness to allow for optimization, benefits of scale	Coordinated hydropower generation, regional power pool, conjunctive use of surface and groundwater, basin-level or multilevel planning, multipurpose infrastructure, integration of natural and built infrastructure, water-related policy harmonization
	Robustness to withstand change and shocks	Well-designed, resilient, storage and flood protection infrastructure, appropriate operating rules, functioning ecological infrastructure, coordinated institutional systems, local community response systems, relevant information systems
Characteristics of Systemic Resilience	**Adaptability** of a system to change	Flexible institutional arrangements, flexible infrastructure design, responsive flood mitigation strategies, policies that facilitate technology adoption and climate smart actions, policy and support that enables livelihood adaptability
	Transformability of a current system to a better system	Flexible policy and legislation, regularly revised strategies, learning institutions that can reorganize, infrastructure systems that can be altered or operated in different ways, community and country resources to enable changes

3 Africa's Water Is Fragmented in Transboundary Basins, Complicating Water Management Systems

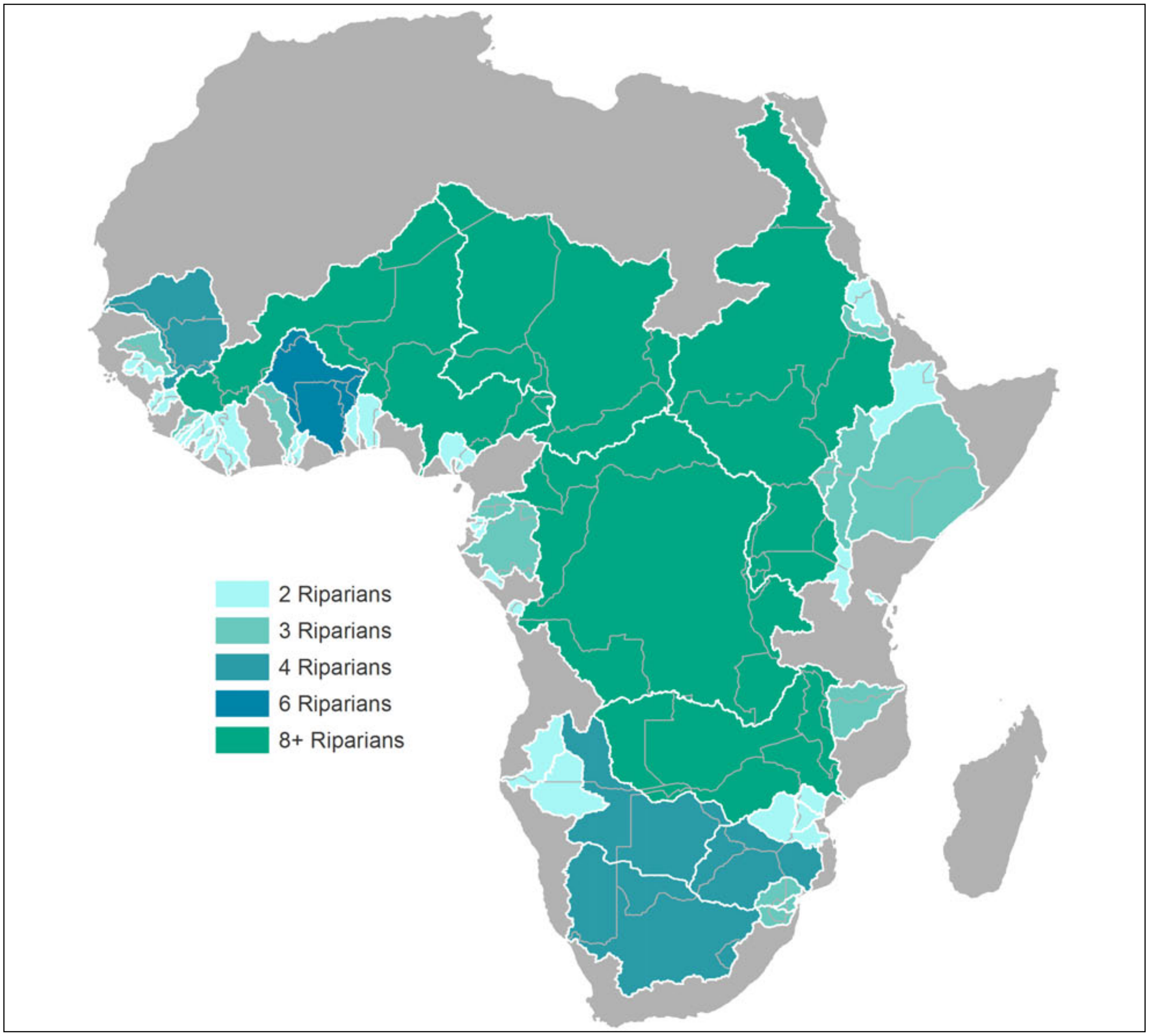
KEY MESSAGES

- Africa's water resources are mostly transboundary which introduces technical, economic, financial, political, and environmental challenges as countries manage and develop their water resources to advance their development and resilience objectives.
- Acting only at the national level limits the degree of resilience countries can build and can have maladaptive consequences. Regional-national coordination is needed.
- The nature of cooperative action among countries depends on the hydrological characteristics of the basin, as well as non-structural factors such as historical legacies and socioeconomic-political contexts.

Transboundary basins cover 62 percent of Africa's total land area. Every African state's territory, except for the island states, contains parts of at least one transboundary river basin (UNECA 2000). Ninety-eight percent of surface water in Africa is within transboundary systems. Annex B provides an overview of five major transboundary basins in Africa, which provide the basis for evidence discussed in Chapter 4. Further, transboundary aquifers underlie 42 percent of the continental area, and serve as an important resource for 30 percent of the continent's population. This overlaying of geopolitical boundaries on structural features of a basin (hydrology, geography, and topography) fragments water management and development. Other structural factors such as economics, historical legacies, population, demographics, major installed infrastructure, and previous legal agreements contribute to the complexities of water management and development in Africa (World Bank 2016b). In addition, water resources allocation and decision making are fragmented between sectors with differing water requirements, impacts, and mandates, and fragmented over time where decisions today may not be appropriate under changing climate and development. These many dimensions of fragmentation result in complex decision-making environments for transboundary basins and should be acknowledged as obstacles to successful cooperation. Moreover, it is important to acknowledge that these challenges are often replicated within a given country due to fragmentation of water resources across provincial lines within national borders.

In shared rivers, lakes, and aquifers, the behavior of each state is interrelated and may pose stresses on the other states. Particularly for river systems, the behavior of upstream states directly impacts amounts, timing, and quality of water available to downstream states. The position of countries in the river system—upstream or downstream, on the main river stem or a tributary—plays a major role in their water management and development decision making. In transboundary waters, capture dynamics are an important driver of political and economic decision making and play an important role in increasing or reducing drivers of fragmentation or unification in cooperative behavior (World Bank 2016b). Examples of frequently observed water management decisions that are affected by capture dynamics include the ability of upstream countries to 'capture' the water for productive use, to store for future use, or to use the ability to control access as leverage with downstream riparians; the fact that downstream riparians may have developed earlier than upstream riparians and claim historical rights to the resource; negative impacts on water quality from deforestation, erosion, or from poorly managed irrigation; and quantities of sediment transport, biodiversity, and fish populations, and related decision points that affect the integrity of aquatic and delta ecosystems.

FIGURE 2 Africa's 63 transboundary river basins



Source: World Bank.

3.1 Coordinated Action at Regional and National Levels Effectively Builds Resilience

To overcome the structural challenges that stem from fragmented water resources and effectively build resilience, water management systems require coordinated action at national and regional levels. As illustrated in the framework presented in this paper (Figure 1) economies, livelihoods, and ecosystems are vulnerable to impacts of climate change on water resources. These vulnerabilities must be addressed at local, national, and regional levels because of the transboundary nature of Africa's water resources. Water management actions—those relating to information systems and sharing, institutions, and robust infrastructure—embed resilience characteristics such as preparedness, adaptability, and connectedness (Table 4). Depending on the hydrology and riparian willingness to cooperate, water actions should be implemented at the local, national, and regional levels. Table 5 describes activities that typically are decided and undertaken at the national level due to administrative and budgetary reasons, and those that

TABLE 5 Water-related actions at national and regional levels can build resilience

Water Management Systems		Level of Required Actions: National	Level of Required Actions: Regional
Information Systems	**Data monitoring and sharing systems**	Data collection, verification, quality control; Use of shared information for preparedness to flood, drought; Data dissemination and sharing with relevant sectors, local stakeholders, and regional entities; Harmonization of national practices with regional protocol	Agreement on data collection and sharing protocol; Regional platform/mechanisms available for exchange
Information Systems	**Decision-support information systems and early warning systems**	Provision of data for calibration; Use of analytical tools for preparedness and robustness development projects; National preparedness plans and information dissemination schemes are developed or harmonized; National plans are informed by basin-wide models and jointly developed tools	Joint development of modelling and analytical tools; Forums for dialogue that use tools for development prioritization and planning; Early warning systems implemented, information disseminated to national or local constituents
Institutional Systems	**Flexible policy and legal instruments**	National law enforcement, policy implementation; Agreement and execution of management actions	Regional policy implementation; Agreement on climate-informed water/benefit sharing, abstraction limits, storage and release protocols, other regional protocol
Institutional Systems	**Institutionally and financially sustainable water resource organizations**	Sub-basin organizations manage local processes, carry out sub-basin level management functions; National structures coordinate, allocate, and develop plans among sectors and ministries; Carry out information and investment functions and communicate with stakeholders for accountability purposes	Agreement on organization mandate; Capacity building within organizations; Financial sustainability measures in place; Working partnerships with national governments, other regional bodies established
Infrastructure Systems	**Basin-scale, resilience-targeted, investment planning**	Develop national plans for water management and development; Tailor and prioritize investments to local needs and norms; Coordination of national project prioritization and planning with regional agreements and processes	Basin-wide dialogue to jointly prioritize interests, evaluate cross-border and cross-sector trade-offs, agreement on regional investment plans that ensure system preparedness, robustness, redundancy, and adaptability; Regional resource mobilization
Infrastructure Systems	**Robust infrastructure investment implementation**	Prepare and implement national investments in collaboration with regional counterparts to share risk, optimize benefits; Operate national infrastructure sustainably, in coordination with other users; Endeavor to restore and maintain ecosystems services and natural infrastructure; Target preparation studies to ensure robustness, adaptability to a changing climate; Carry out stakeholder consultations to ensure optimization of benefits, minimization of impacts	Transboundary coordination in investment planning, implementation, and operation; Prepare, operate, restore joint-infrastructure investments; Enable optimal operation of investments in the region

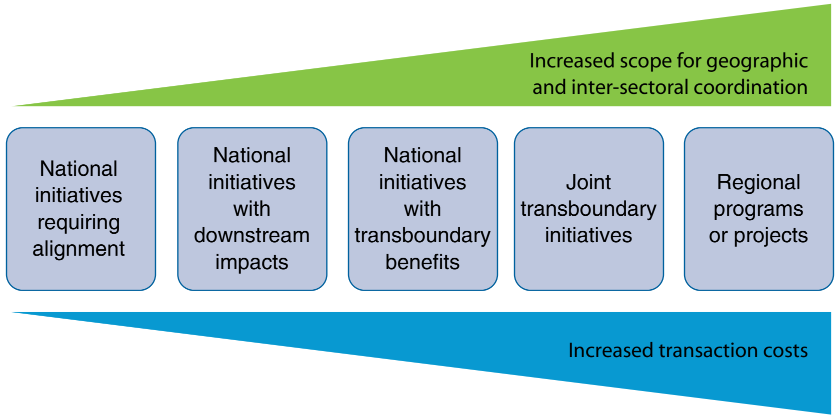
are ideally undertaken at the regional level or incorporate regional perspectives for hydrological reasons. Cooperation among riparian states can be fostered and can in turn enable a more climate-resilient and sustainable development path for the water sector and for the economies, livelihoods, and natural systems of involved countries.

3.2 A Typology of Cooperation and Transboundary Initiatives

While the bulk of resilience-building actions are decided and planned for at the national level as shown in Table 5, the nature of the basin and sub-basin catchments as hydrological units necessitates regional coordination to ensure effective resilience building and avoid maladaptive consequences. Depending on the nature and scale of action, five main types of coordination or cooperation can contribute to building resilience:

- **National initiatives requiring alignment** in water management and information sharing between countries to ensure consistency in approach and benefits to all parties due to intercountry dependencies. Examples include: abstraction from a shared transboundary aquifer, fisheries from a shared lake, water quality management of a

FIGURE 3 Countries can build resilience through a range of different kinds of water management actions of transboundary significance



shared border river, or the establishment of environmental flows along a shared river. Coordination among the riparian countries' national management of the water resources in the interests of all can contribute to resilience by increasing preparedness, robustness, and adaptability of all countries to climate shocks and stresses.

- **National initiatives with downstream impacts** on neighboring countries where the principles of prior notification, no harm, and shared benefit are relevant to ensure coherent and effective management of the entire water resource. Examples include upstream construction and operation of a storage dam for water supply or hydropower that alters the amount and timing of water flow downstream, as well as flood management infrastructure and policies that have flood impacts on downstream countries. Cooperation among countries can ensure that the downstream country can mitigate impacts as well as partake in benefits, and can contribute to resilience by increasing the preparedness, robustness, and adaptability of downstream countries to climate shocks and stresses.
- **National initiatives with transboundary benefits** typically associated with the supply of water or energy (and possibly even food) to a neighboring country, possibly to improve the financial viability of the project. Examples include water supply systems, hydropower plants or even irrigation expansion entirely within a country, with agreed off-take by another country. With cooperation around the contractual and financial arrangements to enable the project, these can contribute to climate resilience by increasing preparedness, robustness, and adaptability of the donor country, as well as the integration and connectedness of the receiving countries.
- **Joint transboundary initiatives** requiring joint decision making, development, and operation of infrastructure systems between two or more directly involved countries, because the project is physically located on or crosses a border between the countries. Examples include a storage or hydropower dam located on a shared river between two riparian countries, an integrated water supply system crossing a national border, or a flood defense system along a river between two countries. Cooperation in planning and implementing the project can contribute to robustness of the project, as well as to improving climate resilience for both countries by increasing their adaptability, integration and connectedness, diversity, and redundancy of the system by enabling a project that would not have been possible without cooperation.
- **Regional programs or projects,** or a coherent portfolio of transboundary projects across the basin, that deliver regional benefits across several countries through cross-border and cross-sector interactions involving water, energy, agriculture, and/or transport systems. Examples include a mega-hydropower project, or a series of hydropower projects in cascade, providing energy into a regional power pool to multiple countries; a transboundary agricultural or extractive corridor requiring multiple water supply and energy generation projects, possibly with processing facilities; and a transboundary basin livelihoods strategy based on multiple smaller projects including watershed management, supply, sanitation, small-scale irrigation, fisheries, and others across countries. Maintaining a transboundary perspective and cooperation across countries and sectors to leverage the opportunities and manage the interactions across the system can contribute not only to the preparedness, robustness, and adaptability of the system, but also increase integration and connectedness, diversity and redundancy, and even transformability of the system by enabling opportunities that would not be possible without cooperation.

This typology of water management actions highlights an important distinction between cooperation and transboundary initiatives. On the one hand, cooperation obviously enables joint and regional projects that can build resilience by providing opportunities that would not otherwise have been possible. Cooperation also builds resilience of national and local projects by ensuring that the preparedness, robustness, and adaptability of riparian countries are improved. Opportunities for geographic and inter-sectoral coordination are greater for regional initiatives compared to nationally focused initiatives; however, the associated transaction costs may also increase, as may the levels of cooperation necessary for countries to be able to identify, distribute, and package benefits in ways that outweigh costs for all involved riparians.

3.3 Trade-offs and Barriers to Cooperation

Despite the many opportunities cooperation around water resources provides, many barriers to cooperation remain. Barriers to cooperation include uneven distribution of resources and needs; difficulty determining reasonable and equitable use of water resources; differences in technical and financial capacity; historical tensions; asymmetrical political economic power; and lack of enforceability of international water laws. These barriers can be reinforced by institutional obstacles such as high transaction costs; environmental, technical, and financial constraints; low national budgets for regional dialogue; long timelines for cooperation processes; differing motivations for diverse stakeholders; imbalanced availability or reliability of information; ever-present possibility of risks of conflict, causing a project to fail at any time; large numbers of stakeholders, which increases fragmentation and dilutes decision making; and lack of legal and institutional coherence, which complicates decision making and implementation.

The above challenges with cooperative management of transboundary basins may be clustered into the following three reasons (Namara and Giordano 2017):

- **Borders, predefined bargaining positions, and water rights.** The creation of mechanisms to manage transboundary waters is almost universally complicated by the upstream-downstream problem associated with water resources management. Downstream countries naturally prefer what has come to be known as the Doctrine of Absolute Riverine Integrity which suggests that every riparian has a right to the use the waters that would naturally flow into its territory (Dombrowsky 2007; Giordano and Wolf 2003), which is further reinforced by the claim to historically established use. Upstream countries, on the other hand, tend toward a position known as the Doctrine of Absolute Sovereignty which holds that a state has the right to the use of any waters that flow within its territories. In Africa, the problem of predefined bargaining positions and upstream-downstream relations is exemplified by the longstanding deadlock in negotiations over the Nile. A doctrine of Limited Territorial Sovereignty has been put forward as a moderating position between the two extreme positions and recognizes the right to reasonable and equitable use of international waters by one riparian state as long as no significant harm is inflicted on other co-riparians. The concept is embodied in the 1997 United Nations (UN) convention on the Non-Navigational Use of Transboundary Waters, but has yet to be ratified and contains no specific guidance as to how the competing principles should be worked out in practice.
- **Water as a zero-sum game and the role of externalities.** A focus on dividing waters rather than overall expansion and equitable distribution of benefits narrows the field in which countries can collaboratively manage their shared resources. Further, the unidirectional flow of water can create externalities, which are direct, non-price-mediated effects on an agent stemming from the production or consumption activities of another economic agent (Mas-Colell, Whinston, and Green 1995). For example, if an upstream state pollutes, some of the costs of that pollution are literally washed down to its lower riparian neighbors. Similarly, dams operated under rules for the benefit of upstream states can change flow patterns and water temperatures (Petr and Swar 2002) in ways that harm downstream state interests. Dam construction upstream can, of course, also create positive externalities through flood control or otherwise regulating flows in ways useful to downstream states. Externalities need not be unidirectional, however. For example, when shipping is possible or internationally migratory fish are present, both up- and downstream states can be harmed or benefited by the choices other riparian countries make in terms of flow maintenance, pollution levels, or fish catch.
- **Transaction costs and uncertainty.** The process of creating formal treaties or agreements such as a Memoranda of Understanding to cooperatively manage internationally shared waters is not trivial, can span over

BOX 5 Five categories of risk perceived by countries that pose as barriers to cooperation (Subramanian, Brown, and Wolf 2012)

Capacity and knowledge—Confidence in ability to negotiate a fair deal; having enough and the correct information and knowledge to do so

Accountability and voice—Deliverability of benefits by the regional entity and co-riparians, often related to trust; having a say in decision making in the governing structures of the regional entity

Sovereignty and autonomy—Ability to act in the best interest of the country without constraints; making decisions independently

Equity and access—Fairness of relative benefits to country, including timing of benefits and costs and obtaining and retaining fair access to river

Stability and support—Longevity potential of the agreement; in-country support of the agreement, including the likelihood of ratification

multiple years, involve significant political and financial costs, and are subject to uncertainties inherent to international negotiation around how agreements will be implemented, as well as the validity and interpretation of data used in implementation, treaty finance, dispute resolution, and more (Fischhendler 2008). The risk of these uncertainties is increased by uncertainties in the material nature of shared water resources including around variability in water quality and quantity and in the vulnerability of resource systems.

Ultimately, countries do not cooperate in the management of transboundary waters until the net benefits of cooperation are perceived to be greater than the net benefits of non-cooperation, and when the distribution of the net benefits is perceived to be fair (Grey, Sadoff, and Connors 2016). Risk perceptions are critical and can be described in five general categories (Box 5), where these perceptions of risk are ultimately barriers to cooperation (Subramanian, Brown, and Wolf 2012). Building trust between riparian states and clarifying risk and opportunity is crucial to facilitate cooperation as it is only where the benefits are perceived to outweigh the costs that cooperation is adequately pursued by the relevant parties (Subramanian, Brown, and Wolf 2012).

Equally, common challenges such as climate change, which impose shared risks and affect shared resources, provide a strong motivation for countries to find ways to overcome barriers of fragmentation. Adopting a long-term vision is necessary for countries to realize that the costs of cooperation, whether in terms of increased restrictions in water allocations or timing of water use or simply transaction costs, can be surpassed by the benefits of cooperation.

Significant development and climate challenges face Africa's water resources in the coming decades; additional fragmentation challenges increase the complexity of managing transboundary basins. There is an imperative to both adopt robust interventions to address the climate development challenge, and to foster cooperation to ensure these interventions enable the widest range of resilience outcomes possible to best serve the interests of all countries and people in a basin. Both imperatives impose transaction costs, presuppose relevant awareness, and require capacity from country water managers and politicians to implement. These imperatives also involve accepting uncertainty in decision making. These process requirements that reinforce the importance of mobilizing support for these processes—external and internal, financial, and political—will help ensure that when cooperation around climate robust interventions is pursued, riparian countries are committed to the process, understand the issues, and can follow through implementation.

4 Transboundary Cooperation Ensures That a Full Range of Resilience Options Are Available to Decision Makers

KEY MESSAGES

- Impacts from climate change are producing water-related vulnerabilities in economies, ecosystems, and livelihood systems across Sub-Saharan Africa.
- Transboundary cooperation around water resources information systems, institutional frameworks, and infrastructure (the 3 I's) allows riparians to respond to and prepare for climate challenges in a holistic manner, to improve water availability, provide protection from water-related disasters, and to preserve natural infrastructure.
- As a result of the resilience built in water management systems via transboundary cooperation—economic systems, livelihoods, and ecosystems are better able to absorb current and future climate-related shocks and stresses and maintain function in the face of it.
- Cooperation provides options for more optimal solutions and for harnessing economies of scale that may not be available through unilateral action.
- Evidence from transboundary basins in Africa shows that interventions around the 3 I's, when planned and implemented in a climate-robust manner, can improve the resilience of the individual countries and of the basin overall to changing hydrological cycles.

Given that most of Africa's water is transboundary, water-related actions are needed at the regional and national levels to overcome vulnerabilities of water-dependent sectors and ensure that the full range of resilience building is possible. Transboundary cooperation around water resources information, institutions, and infrastructure allows riparians to respond to and prepare for climate challenges in a holistic manner that accounts for hydrological realities and optimizes benefits from the resources. Cooperation provides opportunities to harness economies of scale that may not be available through unilateral action. When planned and implemented in a climate-robust manner, interventions around the 3 I's can improve the resilience of the individual countries and of the basin overall to changing hydrological cycles.

Cooperation can also be important in fragile contexts, which are inherently characterized by weak institutions, insufficient information systems, and lacking or degraded infrastructure. Growing evidence suggests that carefully designed water management investments—accounting for shared nature of transboundary waters—promote regional stability and interconnectedness, increase service provision to fragile areas, and can enable an escape from fragility, which are essential for building long-term resilience (Sadoff, Borgomeo, and de Waal 2017). It is important to note that explicit consideration of climate change impacts and vulnerabilities in national or regional water management actions is essential to building resilience. Water management or development action alone—either unilateral or cooperative—may not deliver adaptation benefits, and cooperative interventions may be maladapted if the consequences of climate variability and change are not considered.

In this chapter, evidence from African river basins is used to illustrate how cooperation enables (a) shared and trusted information, (b) flexible and adaptive institutions, and (c) sustainable and robust investments. A series of key assertions are made, each of which is supported by existing or proposed interventions that build resilience in one or more African river basins. Each case presents evidence in following the framework of this paper, illustrating how climate impacts create water-related vulnerabilities in economies, livelihood systems, and ecosystems. Options for resilience to climate change impacts are expanded in those basins by taking cooperative, transboundary actions to address these vulnerabilities.

4.1 Cooperation Enables Shared and Trusted Information

Lack of climate, hydrological, and socioeconomic information poses a critical barrier to effective water resources management and development in Sub-Saharan Africa, which in turn affects the region's ability to cope with and adapt to climate change. Without sufficient information, technical understanding of climate-related challenges is limited, as is the possibility of exploring solutions. Moreover, lack of transparently shared information can fuel mistrust stemming from historical relationships and wider political dynamics among riparians. Cooperation can enable shared and trusted information and build resilience in the following ways:

- Cooperation enables riparians to **use shared information platforms** to effectively respond to water-related hazards.
- Cooperation enables **sharing of data, knowledge, and analytical tools** needed for regionally beneficial development planning.

4.1.1 Cooperation enables riparians to use shared information platforms to effectively respond to water-related hazards

The hydro-meteorological characteristics that lead to floods, droughts, and other water-related hazards are not restricted to national borders, and neither are their impacts; hazard management therefore requires coordinated action among countries in the region. Remote sensing data provide a basis for valuable seasonal and short-term forecasting models. Despite recent leaps in technology, the accuracy of weather and stream flow forecasting based solely on remotely sensed data is limited; models must be calibrated with field data from across the hydrological system. Cross-border sharing of information within an institutionalized early warning system can greatly improve prediction and help avert large losses of lives and property. Although coverage of conflict-ridden areas is usually limited in terms of data monitoring and early warning outreach, inclusion of these areas becomes even more important given the amplified vulnerability of populations due to conflict and the need to be able to accurately identify, communicate with, and aid populations and areas that will potentially be affected. The longer term, historical trends emerging from shared data enable countries to jointly assess climate trends that may require future adaptations to system operation and disaster response regimes. Shared information platforms are therefore fundamental for building resilience through improved disaster preparedness, increased robustness of infrastructure, and overall longer term adaptation to water-related hazards. However, to gain these benefits, the specific information requirements to monitor and interpret the impacts of climate change should be included in the shared information platforms. If they are not, sophisticated monitoring systems may miss the potentially changing characteristics of these hazards.

Examining the evidence: Shared information platforms in the Nile, Lake Chad, and the Incomati River

Eastern Nile flood forecasting and early warning saves lives and secures livelihoods. The Nile River Basin is characterized by high seasonal and interannual flow variability, and experiences regular floods and droughts. This variability along with floods and droughts is projected to become more intense and frequent with climate change. Flooding is a major risk to lives and livelihoods.

To address this increased flooding vulnerability, a regional cooperative effort coordinated by the Nile Basin Initiative (NBI) has created an effective system that links a wide range of stakeholders to work together to address flooding and its impacts in highly vulnerable regions of Ethiopia, Sudan, and South Sudan. Daily flood level monitoring from local stations is combined with rainfall data and hydrological monitoring to produce real-time flood regional forecasting. Since 2010, daily, weekly, and seasonal flood forecasts are disseminated on the web, via e-mail and mobile phone messaging to national ministries of water and national flood committees, local governments, communities, and humanitarian organizations. Coordination systems are also established within countries, where ministries work with local governments to effectively enact flood planning and response. About 150,000 people in high-flood risk areas in Ethiopia and 200,000 in Sudan and South Sudan receive early warning messages during the flood season as well as daily alerts; a further 1.7 million people indirectly benefit from this service, and are better able to reduce their risk of flood devastation. Among those that benefit are the subsistence farmers and livestock pastoralists who are at highest risk, who can now make informed decisions on planning cropping for the season, avert loss of lives and livestock, reduce property damage, and minimize disruption of productive activities, and when needed, plan for temporary migration.

During peak flood season, a growing number of institutions at subnational, national, and regional levels, including UN agencies, rely on the NBI's daily forecasts to provide timely relief assistance. As funding becomes available, the NBI continues to enhance its flood forecasting capability by incorporating additional weather, flash flood, and climate models, while tailoring its updates to better serve National Flood Forecast Centers. It also continues to expand its forecasting to yet unserved urban and rural areas of the region that are at high flood risk. The flood early warning system tools also inform the Nile DSS, a comprehensive data-analysis framework jointly developed by the NBI and Nile countries, to develop agreed upon 'climate change flood scenarios' to improve long-term water resources development planning.

A regional early warning system in Lake Chad will enable countries to comprehensively map water-related risks and response to hazards in a timely manner. The Lake Chad Basin is prone to extremes of riverine flooding and prolonged droughts, putting at risk the lives and livelihoods of a large number of communities. These extremes are expected to increase over the coming decades due to climate change, while ongoing uncertainty about the hydrology of Lake Chad is exacerbated by a lack of transboundary cooperation. Technical capacity necessary for hydromet monitoring and seasonal and short-term forecasting in the basin is limited. Climate risk in the basin is compounded by the fact that country borders around the lake are porous, with nomadic communities constantly shifting base without a sense of national belonging, making it extremely challenging to identify and reach vulnerable communities before and after hazard events. Further intensifying the challenge is the volatile security situation around the basin, which reduces prioritization of water management systems in the face of more immediate security issues; limits accessibility for installing and maintaining monitoring equipment, conducting training for building human capacity, and overall top-down and bottom-up communication for hazard warning and response; and limits overall effectiveness and sustainability of implemented water management systems.

In this context, countries in the basin have realized the need to share the limited data that each possesses to piece together a more complete image of the risks that are faced by the communities living around the lake. In addition, a cooperative approach would also allow for better communication of flood and drought warnings to communities occupying vulnerable regions, irrespective of national territory, at any point in time. The Lake Chad Basin Commission (LCBC), with support from the Global Water Partnership (GWP), is developing an early warning system for the Lake Chad Basin, beginning with a pilot project in the Logone sub-basin. The system will establish much needed information and communication infrastructure on weather, climate, water, and disaster risks management (GWP 2016), and is an example of how a 'no/low-regret' project can be key to enhancing water security and climate resilience in the basin by enabling better agricultural planning and emergency preparedness and response. In addition to serving as a monitoring and alerting system, the project aims to use information generation and application as a way to increase transboundary cooperation, particularly capturing the vast amounts of remote sensing data available in the public domain, which can provide valuable information as efforts continue build national capacity to gather on-ground data.

Transboundary cooperation around sharing information is a precondition for disaster management in the Incomati River, even at the local level. The Incomati River in southern Mozambique showcases how the use of basin-wide information through a public-private consultative approach can improve flood risk management (FRM) at the local level. Southern Mozambique is particularly prone to flooding generated by a combination of climate factors and manmade factors triggered by upstream countries, South Africa and Swaziland. With increasing intensity and frequency of floods predicted as a result of climate change, there is an increased need to address the vulnerabilities of subsistence farmers.

Floods on the Incomati are managed at the local level, and the Climate Resilient Infrastructure Development Facility (CRIDF) is supporting local stakeholders to access and utilize basin-wide data to build local resilience to climate shocks and stresses. CRIDF has adopted a public-private consultative approach to effectively build micro-level engagement for warning dissemination, resulting in improved FRM for a broad spectrum of stakeholders. The de facto basin flood management committee for the Lower Incomati is governed by a memorandum of understanding between Southern Regional Water Administration (ARA-Sul), private sugar estates, the Mozambique National Roads Administration or Administração Nacional de Estradas (ANE), the Manhica Local District Planning and Infrastructure Division, and Electricidade de Moçambique. Using a 2D hydraulic river flood model, FRM infrastructure options have been identified that demonstrate the economic and financial benefits that sharing flood risk will create among the basin stakeholders. Illovo and Tongaat Hewlett, major sugar producers in Mozambique, together with their smallholder farmers, benefit from the improved climate-related flooding information as they are better able to tailor their irrigation planning. Similarly, the river flood model is now being used by ANE for road design, to reduce flooding impacts on local communities. Based on the success of this local application of flood modeling and stakeholder mobilization, the three countries of the Incomati Basin—South Africa, Swaziland, and Mozambique—are working with CRIDF support to scale up the project to develop a regional real-time flood forecasting system for the basin, to enable a more informed understanding of potential flood events and mitigate associated risk, including around safe operation of specific dam infrastructure during floods. Transboundary information systems which improve the safe robust operation of reservoirs for the protection of agricultural communities and property increase the resilience of the people in the basin.

4.1.2 Cooperation enables sharing of data, knowledge, and analytical tools needed for regionally beneficial development planning

Beyond reducing disaster risk through improved forecasting and response, cooperation among countries enables sharing of data, generation of knowledge and joint development, and use of analytical tools to facilitate longer term development planning for improved climate resilience. Shared information helps states develop a common understanding of water management issues facing the basin at present and in the future, and collaboratively developed basin-level planning tools can help riparians manage competing uses under different climate scenarios by evaluating trade-offs and jointly deciding ways of optimizing water use and sharing of benefits. Such analysis and dialogue forms the basis for formulating basin-level water resources management and development-related policies and plans that are resilient to climate change. With increased hydrological uncertainty and increased variability due to climate change, the ability to create and sustain basin-level water management plans that are robust to changing hydrological conditions is crucial. Importantly, to build resilience, these information platforms need to acquire and provide the relevant climate and related information, as well as the approaches or methodologies to confidently include this information in decision making, even when climate projections are uncertain. Where this is not done effectively, the resulting planning tends to ignore future climate changes or only provide a cursory assessment of the impacts of climate on decisions. The likelihood of maladapted outcomes then increases significantly, due to what may be referred to as a maladapted information platform.

Furthermore, a common understanding of shared climate risks and resilience-building opportunities is often derived from taking a benefit-sharing approach, rather than a rigid water allocation approach; an improved understanding of risks and opportunities can steer countries to direct longer term basin-level planning toward more water-efficient, less water-dependent systems, which ultimately contributes to reducing vulnerabilities of economies and societies and builds systemic resilience. Inclusion of socioeconomic considerations, including vulnerability due to fragility and conflict in basin-level planning, can help target the benefits from water resources to break the cycle of fragility and vulnerability. Also importantly, transparency in monitoring and participatory data analysis and interpretation is necessary for building trust and confidence on the basis of which countries develop a common understanding and can embark on collaborative, forward-looking, resilience-building development.

Examining the evidence: Shared data, knowledge and analytical tools enables regional development planning in the Lesotho Highlands, Nile, Zambezi, and Niger Basins

Information sharing provides the basis for countries to engage in common infrastructure in the Lesotho Highlands Water Project. In the Orange-Senqu Basin, where climate change impacts are predicted to create drier conditions for the lower basin, information sharing set the stage for a successful project to overcome water supply vulnerabilities by sharing water resources and boosting the economic capacity of the region. The Lesotho Highlands Project in the Orange-Senqu Basin is one of the largest and most intricate transfer schemes in the world, moving water from the Upper Orange River in Lesotho to the Vaal River in South Africa. At the start of the negotiation for the project, there was only limited information available regarding the quantity of water available. The countries approached the basin's hydrological models from differing viewpoints, and hence held different assumptions that impeded their reaching an agreement on resulting water availability estimates. Over time, sharing of information about water sources and flow built trust among countries and provided the basis for making technical decisions on project design and benefit sharing—including provision of water, water tariffs, hydraulic and transportation infrastructure, and hydropower—lead to convergence around the terms of an agreement on the Incomati. Ultimately, three dams were constructed, as well as a series of interconnected pipelines, and subsequent phases of the project are still ongoing. Information sharing at the early stage of negotiations between riparian states was key for the states to agree on an appropriate strategy to develop the basin.

Another example illustrating the need of information sharing as a preliminary factor to allowing common interventions is that of the Orange River Basin's IWRM Plan. While the lack of shared information first deadlocked the conversation around a common IWRM vision, sharing of data among countries, conducting joint analyses, and conducting informed dialogue helped South Africa and Namibia understand how IWRM principles could be adopted to collaboratively manage their shared water resources to generate mutual benefits. Subsequently, the two countries agreed on a model for a hydrological and system analysis of the basin, which served as a basis of a successful IWRM plan.

In both the Lesotho Highlands Project and the Orange-Senqu Basin, information sharing provided the foundation for building cooperation, diversity, and redundancy into water supply and increasing integration and connectedness of economic systems throughout southern Africa.

Nile DSS enables strategic decision making for climate-resilient development planning. On the NBI platform, the Nile countries have developed a comprehensive Nile DSS, comprising an information management system, a regional river basin modeling system, and a suite of analytical tools to support multi-objective analysis of investment alternatives under a range of different scenarios including different climate futures. With predicted changes to the already highly variable hydrology of the Nile Basin, the ability to take into account a range of climate scenarios enables major infrastructure financing projects to better understand the various potential operating environments they might face. Informed by the DSS, countries are able to conduct a more comprehensive trade-off analysis as they jointly evaluate investments of transboundary significance and analyze the contribution of a particular investment to the resilience of the region's economy, livelihoods, and natural resources.

Analysis using the DSS shows that while there is considerable irrigation and hydropower potential in the basin, national plans for irrigation expansion in the long term can only be met through cooperative management of the Nile that carefully considers the inter-sectoral trade-offs of water use, emphasizes smart agriculture techniques, and includes a landscape of improved regional trade and integration. Through these jointly developed basin planning tools, countries are able to build a shared understanding of why these water-related and beyond-water actions are critical for achieving sustainable growth and climate resilience, and based on that, jointly prioritize investments to move forward with at the national level. The benefits of the DSS were effectively impossible to comprehend 20 years ago when countries were completely driven by inward-facing perspectives.

Further, a basin-wide hydromet network designed by the NBI under the directive of the Nile countries is envisioned to provide high quality, long-term data to better calibrate the Nile DSS and to improve accuracy in planning. The NBI is working with national-level hydromet agencies to ensure that the regional plan is aligned with national plans. National hydromet agencies report to different ministries in different countries; the NBI has developed a uniform basin-wide protocol for data and information sharing and is helping establish working partnerships with these agencies. The NBI's effort to strengthen hydromet monitoring in the basin also includes bringing human capacity up to the same level across different countries to enable uniform operations across the basin-wide network; ensuring that financial sustainability mechanisms are in place not only to set up monitoring stations but to sustain operations and maintenance regimes to avoid critical gaps in monitoring; analyzing data to generate information useful to its wide ranging stakeholders including the public, different ministries, disaster risk management agencies, and academia, among others; and mobilizing resources to implement the hydromet plan through regional or national initiatives. The comprehensive emphasis placed on monitoring station infrastructure, capacity, policy, and finance would not have been possible without a cooperative effort among basin countries. Cooperation among countries can enable transparent monitoring for other critical variables such as flow levels, evapotranspiration, water quality, and sediment loading—all of which can be used to ground the modeling done through the Nile DSS.

The Zambezi Water Resources Information System (ZAMWIS) aims to strengthen information sharing to help states adopt better disaster prevention and longer term management and development strategies that build resilience and avoid maladaptation to climate change. Cooperation through ZAMWIS is strengthening information sharing among Zambezi basin countries. As illustrated in the Nile Basin and Incomati cases, hydro-meteorological monitoring and prediction systems can provide critical early warning capacity to protect livelihoods and infrastructure from increasing hydrological variability, increasing floods, and prolonged drought. Through information sharing, ZAMWIS will provide countries with the necessary data to forecast and prepare for disasters. Once the ZAMWIS tool is fully operational, floods in the Zambezi Basin will be monitored by the Zambezi Watercourse Commission (ZAMCOM) Secretariat. The tool will integrate free radar satellite images from the Copernicus Sentinel-1 mission into maps to visualize the current state of floods in the region and also forecast likely future flooding. ZAMCOM is working to integrate this feature of ZAMWIS into an operational DSS for flood forecasting and early warning in the Zambezi Basin (Tøttrup 2015). By sharing on-ground data and cooperative usage of satellite data, ZAMWIS is helping countries improve their understanding of the climate challenges faced in the basin at both national and regional levels. Ultimately, countries hope that they are better prepared for disasters, and that incidents such as the 1978 flood—in which lack of information sharing between Zambia and Mozambique foreclosed disaster prevention options, leading to 45 deaths and over 100,000 being displaced in the Lower Zambezi, and caused US$62 million worth of damage—can be avoided. Finally, it is also expected that this more comprehensive understanding will help states to adopt more resilient policies, as well as make more resilient investments in water infrastructure.

Rising drought impacts in the Sahel have led Niger Basin countries to address drought risk in basin development planning. Climate variability and droughts have had devastating impacts in west and east Africa. Although emergency aid has reduced damage to life and property during more recent droughts, past incidents such as the 1970–1973 drought and resulting famine killed up to 250,000 people and decimated two million heads of livestock (Kandji, Verchot, and Mackenson 2006). Impacts at scales such as these generated regional awareness about the importance of monitoring climate and water data, and using it for forecasting. As a result, countries in the region started to strengthen their monitoring network for data collection, evidenced for example by the establishment of the Agrometeorology, Hydrology, Meteorology Regional Center (AGRHYMET), a specialized institution of the Permanent Interstate Committee for Drought Control in the Sahel (CILSS), that focuses on drought monitoring and associated capacity building. In another regional initiative, the Niger Basin Authority (NBA) has provided a framework for cooperation among riparian countries toward improving water information systems in the basin (WHYCOS n.d.).

In addition, the countries have established the NBA Observatory, in which participating countries agreed to a data exchange protocol that binds countries to share hydrology, environmental, and socioeconomic data. This protocol constitutes the basis of the observatory to serve as a reliable and sustainable data exchange platform of the NBA. Through the nine national units anchored to this platform, the observatory can appropriately collect, compile, analyze, and disseminate water and climate data, as well as disseminate reliable information to governments and other stakeholders. Key services provided by the observatory that contribute to resilience-building actions include issuing flow forecasts; summarizing and analyzing planned water abstractions; and availing hydrology and socioeconomic data to inform riparian dialogue water management related issues, trade off evaluation at the basin scale, and preparation of basin investment plans.

4.2 Cooperation Enables Flexible and Adaptive Institutions

Cooperation around the management and development of transboundary water resources requires platforms for intercountry engagement and sharing knowledge, commonly provided by river basin or other regional organizations, as well as agreements or instruments that enable collaborative action. These institutions typically balance sovereign development priorities with transboundary actions or collaboration needed for building resilience, often within an environment of limited information, constrained resources, and inadequate capacity at both national and transboundary levels. To remain relevant under changing climate conditions, these transboundary organizations, agreements, and instruments need to have the flexibility to adapt as future conditions demand. Cooperation can enable flexible and adaptive institutions and build resilience in the following ways:

- Cooperation enables riparians to **align policy and legal instruments** to respond to and plan for climate change.
- Cooperation helps regional organizations **incorporate learning, flexibility, and adaptation** into the technical and strategic services they provide riparian countries.

4.2.1 Cooperation enables riparians to align policy and legal instruments to respond to and plan for climate change

Each country in a transboundary basin develops institutional arrangements that suit its own development priorities, national and subnational institutional arrangements, and historical context. When institutional arrangements are not conducive to collaboratively responding to development pressures or climate impacts, countries might unintentionally work against one another and generate maladaptive impacts. National water management policies related to watershed protection, monitoring and managing quantity of water withdrawals from the system, and minimizing water quality impacts must be well aligned with regional policy to ensure appropriate management of the water system. Sectoral policies relevant to the watercourse, such as operation of water storage or conveyance infrastructure, freshwater fisheries management, tourism development, land-use and forest policy, irrigation policies, and hydropower operation all see improved sustainability, efficiency, and resilience when aligned at the regional level. Proactive alignment of regional and national policies is needed for countries to sustainably build climate resilience. This will become increasingly important as climate impacts accelerate and as development pressure and water-stress constraints increase.

These instruments need to also consider the uncertainty associated with a changing climate, and should therefore be flexible enough to evolve as climatic and hydrological conditions change, as well as have appropriate mechanisms to trigger this evolution, based on relevant information. Where policy or legal instruments are too rigid or are difficult to alter in response to changing climate conditions, intercountry water allocations may not be achievable, water quality loadings may cause unacceptable degradation of water resources, harvesting of fish or other ecosystem goods may be unsustainable, or the assumed shared benefits (such as hydropower) may no longer be available. This is likely to cause tensions as one or more riparian countries are negatively impacted.

Examining the evidence: Cooperation enables policy and legal instrument alignment in the Southern African Development Community and Eastern Nile

The Southern African Development Community (SADC) has driven a process of water policy alignment between member states, leading to tangible improvements such as improved water quality in the Vaal-Orange river system. The SADC Water Protocol fosters alignment among countries sharing water resources in the region, enabling countries to leverage shared benefits and reduce potential disputes. The protocol provides a valuable basis for ensuring consistent water-related climate change policies and approaches in SADC, which are prioritized under the SADC Regional Strategic Action Plans.

With climate change projections in the SADC region predicting increased hydrological variability, the ability to cooperate on water management policies will hopefully moderate the potential for increased tensions between countries over these resources.

For example, Lesotho, South Africa, Botswana, and Namibia are consistent in terms of water allocation and licensing, water quality regulation, and water pricing, thereby enabling the four countries to adopt a joint plan for IWRM, coordinated by the Orange-Senqu River Commission (ORASECOM). Among other outcomes, this plan targets improving water quality and assuring environment flows in the Vaal-Orange river system. Water policy consistency and alignment across borders is critical for issues such as water quality management, where downstream riparians are impacted by upstream riparian's discharge, or for maintaining environmental flow regimes where consistent upstream and downstream policy is required to ensure sustainability.

Going forward, this alignment will allow the countries to coordinate their responses to salinity problems that occur during a dry season or other low flow conditions. It will also allow them to coordinate important commercial irrigation projects and the development of the estuary as a tourist destination in the Lower Orange River. Coordination thus facilitated by aligned water resources policies across countries in the basin has developed a cooperative working relationship guided by collective risk management and a view to improving basin-wide well-being, traits which will be valuable in a more resource-limited future.

Agreement on regional dam safety standards in the Eastern Nile enables safeguarding of infrastructure and downstream populations in the face of increasing extreme events. Through the NBI platform, the Nile countries have agreed upon regional dam safety standards for big and small dams in the Eastern Nile, safeguarding against threats such as breaches that put at risk downstream populations in the basin, irrespective of national borders. With predicted increases in extreme weather events that could lead to increased flooding, dam safety will be increasingly critical as the impacts of climate change are felt. The governments of Ethiopia, Sudan, and South Sudan have agreed on principles for dam design and developed a shared understanding of the need for coordinating operating rules, while recognizing the need for flexibility to account for and adapt to increasing hydrological variability and change. Countries affirmed their commitment to the regional dam safety agreement by establishing national dam safety units in each country to implement the proposed guidelines, ensure that national level processes are aligned to regional commitments, and facilitate that neighboring countries coordinate with one another in dam planning, operation, and maintenance. To ensure effective implementation, which includes the need for leveling implementation capacity across countries, NBI has provided on-the-job training to dam operators from all three countries and worked with them to develop technical field guides on dam safety. To continue to build long-term professional dam safety capacity, the NBI has developed a dam safety training module for Eastern Nile universities to build capacity of technical personnel. In a region like the Eastern Nile where hydropolitics is complex and ever evolving, these steps to establish functioning regional-national linkages for dam safety are a tremendous accomplishment, and contribute to ensuring that investments critical to economic growth and climate resilience are robust.

4.2.2 Cooperation helps regional organizations incorporate learning, flexibility, and adaptation into the technical and strategic services they provide riparian countries

Effective transboundary organizations—with bilateral, basin, or regional scope—that facilitate cooperation allow countries to jointly address issues that cross borders, whether this is related to the flow of water, goods, or people. Depending on the basin, such organizations may have different levels of capacity or legal recognition, yet they have proven to be valuable in fostering cooperation, developing joint infrastructure projects, or providing a platform for sharing information and facilitating dialogue. These institutions also address climate change, a transboundary issue, through knowledge creation and incorporation of climate planning into development activities. Successful cooperation around these activities builds intercountry trust, which further strengthens the cooperation that will be necessary as climate and development impacts intensify. Transboundary institutions that enable climate preparedness, adaptability, and integration are the key to leveraging diversity among countries, and act as the catalyst for transformability of transboundary water management under a changing climate.

The uncertainty of climate change impacts on future water resources necessitates that flexibility is incorporated into the way in which water is managed in a basin. African countries increasingly understand that without adaptive agreements in transboundary basins, overseen by organizations that are able to learn from their own experience and that of others, countries may become locked into particular water development futures which cannot be supported by the changing water resources. For example, a country may be disadvantaged when water availability and hence, opportunities for power generation, shifts temporally and/or spatially within a catchment, possibly even leading to transboundary conflict (Dinar et al. 2010). At the extreme, new constraints or opportunities may emerge as climate changes, and without flexible, learning, and adaptive organizations, the historically relevant management paradigm will become outdated and lead to inappropriate or maladapted decisions.

Despite the uncertainty in future climate, countries can avert conflict by flexibly designing their water resources institutions around agreements that reflect relative quantities rather than absolute quantities of water, thereby allow shifting allocations as climate changes occur; adaptive triggers that require renegotiation or reconsideration of allocation when climate conditions change significantly; and cooperative institutions that provide a platform for multi-country engagement to monitor and effect these changes. To be effective, these require appropriate information management systems to observe changes as they occur and mechanisms to prompt response to changes (Dinar et al. 2012). Flexible agreements and adaptive organizations are critical to enable robustness and adaptation to changing climate, as well as more fundamental transformation to changed conditions.

Examining the evidence: Cooperation helps regional organizations incorporate learning, flexibility, and adaptation into technical and strategic services in Lake Chad, Inco-Maputo, and Zambezi Basins

Transboundary agreements among states in the Lake Chad and Inco-Maputo Basins demonstrate benefits of flexibility in adapting to changing climate. The flexibility of an international agreement on shared water is key to ensure that states will be able to adapt as needed to a changing reality. With projected increases in hydrological variability in the Lake Chad Basin, this flexible characteristic of water-related agreements allows states to monitor exogenous changes and to adequately make the necessary changes to the agreement to ensure that the agreement's underlying objectives are achieved.

The Lake Chad Water Charter is an example of such flexible agreement. The charter takes into account climate variability and change in describing equitable and reasonable use of water in the basin. The Water Charter, a binding document with basin-wide coverage, sets out the rights, obligations, duties, restrictions, processes, and procedures pertaining to proper management of the Lake Chad resources. Chapter 2 of the Water Charter outlines 'Quantitative Management of Surface and Groundwater Resources', and aims to build an equitable and reasonable use of water throughout the basin; Article 13 is dedicated to the factors and criteria to be used when determining the States Parties' usage, several of which look at the state of climate variability and climate change. The nature of this multi-criteria list means that the charter fosters flexible water and benefit sharing agreements that can respond to changing conditions. It should be noted that while the Water Charter was signed by Heads of States of six member countries in 2012, it awaits ratification by two-thirds of the member states before it comes into force and measures such as flexible water allocation balanced by sharing of water-related benefits can be implemented. By actively incorporating flexible water allocation into the proposed agreement, the Lake Chad Water Charter is a more robust and adaptable water management instrument, making the basin organization and countries better prepared for a more hydrologically variable future for the basin.

Conversely, lack of flexibility can lead to a rise in conflict over increasingly uncertain water availability in the future due to climate change. An example of lack of flexibility in an agreement is that of the Inco-Maputo agreement between Mozambique, South Africa, and Swaziland, where a fixed minimum flow target is set for the South Africa-Mozambique border. In this agreement, riparian states have agreed on a fixed flow regime for the river. This artificial fixed flow is possible only because of the dam constructed on the river that regulates the flow. While this agreement acknowledges a need for flexibility to certain exogenous changes including the evolving socioeconomic needs of riparian states, in particular with regard to the downstream riparian, Mozambique, there is no leeway for climate adaptation, which will likely become a point of contention in the future and hinder necessary adaptation. While the process of cooperation and negotiation among the countries is lauded as an institutional success, it still has much room for improvement in terms of its ability to build resilience to a changing climate.

The Zambezi River Authority (ZRA), with its mandate to operate existing and scope out new hydropower projects on the Zambezi River, has provided a mechanism for Zambia and Zimbabwe to overcome historical differences and harness shared benefits. The ZRA, a jointly and equally owned bilateral corporation created by Zimbabwe and Zambia to operate and maintain the Kariba Dam on the Zambezi River as well as to identify new hydropower generation opportunities, has contributed to building the relationship between the two countries through energy production. By focusing on delivering energy that is much needed for both countries, through arrangements most suited to the political economy context in the basin (each country has its own power station on either bank of the river), the ZRA has enabled Zambia and Zimbabwe to overcome contentious issues ranging from historical differences to contemporary disagreement relating to the management of the Kariba Dam.

The ZRA has enabled the two countries to invest in additional shared hydropower projects, such as the Batoka Gorge Hydro Electric Scheme (HES). The planned Batoka Gorge HES has been designed to provide sufficient energy for more than 1.2 million households, or around 1,600 MW. The scheme was conceived in 1961 as part of a cascade with the original Kariba Dam complex, but was stalled by a disagreement between the two countries regarding a historical debt related to the Kariba Dam. Analysis facilitated by the ZRA estimated losses of US$7 billion in foregone electricity sales along with massive subsequent costs of up to US$45 billion to the region's economy.

This analysis by the ZRA drove the two countries to move forward with the Batoka HES, ensuring that ZRA carefully considered projected drier conditions and increased variability into account while designing the scheme to make it robust to future climate, while in turn, the electricity generated from the scheme would create manufacturing and service-oriented jobs to build a more climate-resilient economy.

A Joint Operating Technical Committee (JOTC) in the Zambezi Basin enables Zambia, Zimbabwe, and Mozambique to optimize planning and operation of reservoirs in cascade to address multiple objectives. The JOTC is an important contributor to improved operations allowing for better coordination of the Kariba Dam and Cahora Bassa Dam on the Zambezi River, with potential future coordination to include the Iteze-Teze on the Kafue River, a tributary to the Zambezi. The shared governance provided by the JOTC contributes to a more coordinated operation of the Cahora Bassa Dam, based on upstream information and alignment with flows from the Shire in Malawi. This coordination allows dam release to support functioning of the Zambezi Delta, upon which ecosystems and livelihoods depend. This multilateral cooperation in operating hydropower generation infrastructure lends extremely valuable adaptability and therefore resilience to future climate changes, which include greater hydrological variability and likely reduced water availability, amidst increasing energy demand from all riparian countries in the basin.

4.3 Cooperation Enables Sustainable and Robust Infrastructure

Built and natural infrastructure investments play a critical role in smoothening variability and reducing impacts of water shocks that increase with climate change. Water infrastructure development options exist in transboundary basins that countries cannot finance, design, implement, or optimally operate alone. Compared to those advanced unilaterally, investment options that are cooperatively identified, developed, or operated are typically more robust to climate, due to incorporation of basin-wide information and consideration of cross-system interactions, or more financially viable due to pooling of finance or increased ability to attract investment financing. Incentives for preservation and restoration of natural infrastructure are also often realized regionally. Cooperation through transboundary institutions, based on shared and trusted information, supports the development, restoration, and operation of these schemes, building resilience at both national and regional scales. Cooperation enables sustainable and robust infrastructure and builds climate resilience in the following ways:

- Cooperation enables **investment planning at basin scale and advances a portfolio of projects** that can enhance preparedness, interconnectedness, and diversity/redundancy in water management systems;
- Cooperation enables **improved design, operation, and restoration** of built and natural infrastructure, enhancing system robustness.

4.3.1 Cooperation enables investment planning at basin scale and advancing a portfolio of projects that can enhance preparedness, interconnectedness, and diversity/redundancy in water management systems

Unilateral advancement of individual infrastructure projects in a basin may have impacts on the viability of other projects, as well as potentially foreclose more climate-robust development alternatives elsewhere in the basin. National planning alone cannot adequately consider these impacts. Taking a basin-wide systemic approach to infrastructure development and operation allows riparians to evaluate and select the most climate-robust infrastructure to support different development pathways across the basin in different riparian countries, harness synergies from cooperative planning and coordinated operation, and avoid unintentional negative externalities.

However, cooperation alone is not adequate to ensure climate-robust investments and infrastructure systems. Due to the long-lived character of water resources infrastructure, this planning needs to be based on data and analysis that translates the uncertainty typical of climate change projections into information that builds confidence for climate-robust decisions. This relates to both the design of the infrastructure system and to the flexibility in its operation to adapt to future changes. In the absence of this usable climate lens on infrastructure planning, the likelihood increases of developing schemes that do not deliver the expected benefits and are therefore inappropriate or not sustainable.

Examining the evidence: Cooperation enables investment planning at basin scale in the Orange Limpopo Basin, Lesotho Highlands Water Project (LHWP), the Niger and the Nile Basins

A flexible, integrated water transfer system ensures supply in the Orange-Limpopo Basin. The region of Gauteng includes the economic hub of Johannesburg, a key economic hub of South Africa. Gauteng is supplied by an integrated water transfer system that links a number of rivers on the South African Highveld, including the LHWP. Because this is a flexible integrated system, it diversifies the sources of water into areas with different climate regions of southern Africa. The interconnected nature of the system allows considerable flexibility in operation, thereby reducing the otherwise vulnerable economic heartland of the country. This adaptability and flexibility builds infrastructure resilience, and reduces the GDP impacts of climate shocks or stresses in a particular climate zone. The results of a study conducted for the National Treasury suggests that "climate change impacts in one region can, for example, be offset by the increased transfer of water from another region or basin potential less impacted by climate change. Additional resilience is provided in the economic model which allows for water transfers between economic sectors. The result is that the negative impacts of climate change in the water sector do not necessarily translate through into large economic impacts, at least in terms of water resource allocations, that is, not taking into account potential flooding impacts. This has significance for water resources planning and infrastructure development in Africa going into a highly uncertain future."

Ultimately, cooperation around infrastructure development provides additional alternatives that are not solely available to countries. While these may not always be more robust to climate change, there will undoubtedly be situations where climate change relevant analysis will indicate that these are more robust to the projected and/or uncertain climate future that countries individually and jointly face.

The LHWP led to significant financial savings and reduced the cost of water security through transboundary water transfer. Cooperation between South Africa and Lesotho helps the two countries enjoy efficiency gains in their management of water; Lesotho received a financial inflow that can be used positively for the socioeconomic growth of the country, while South Africa diversifies its supply of water to a source under a different climate regime. This diversification also increases the climate resilience of South Africa and of the dry Gauteng region to climate-change-related water risks.

South Africa receives water from Lesotho, paying its neighbor more than ZAR 30 million per month. This amount represents almost half of the money Lesotho would have saved, had South Africa invested in a transfer scheme purely within its own borders. The revenue earned by Lesotho amounts to nearly a quarter of Lesotho's export earnings (Muller n.d.).

The LHWP is overseen by the Lesotho Highlands Water Commission (LHWC), an institution which was created under the Treaty of 1986. The LHWC is responsible and accountable to the two governments for the overall implementation of the LHWP. In this regard, it advises, monitors, and has approval powers on activities of the Lesotho Highlands sales to the economic heartland of Johannesburg, and was able to raise significant debt finance for the construction of the project from commercial finance institutions.

Niger Basin's Sustainable Development Action Plan (SDAP) and the Climate Resilience Investment Plan (CRIP) demonstrate the ability of the NBA to serve as the platform to plan climate-resilient investments in the Niger Basin. The Niger Basin ranks among the most variable regions of the world for inter-decadal climatic variability, transitioning quickly from dry to wet periods (Ghile et al. 2014; Grijsen et al. 2013; NBA and World Bank 2014). Droughts and floods have had devastating impacts in the past, and models indicate a wetter and warmer climate for the Niger Basin with an increase in temperature and uncertainty in future precipitation patterns. Further, projections suggest an increase in the frequency and intensity of disasters. All these factors reveal the need for investments in water storage and use to improve basin preparedness. If accompanied by sound IWRM these developments could contribute toward economic growth and improvement of livelihoods (World Bank Group 2015).

Within this hydro climatic context, the NBA is a good example of how cooperation in a basin advances planning and fosters countries agreements in prioritized investments. After the establishment of the NBA in 1987, the authority served as a dialogue platform to prepare and endorse the 2007 SDAP. The SDAP is organized in three components: (a) protection of resources and ecosystems; (b) development of socioeconomic infrastructure, including infrastructure of transboundary nature (anchored in Fomi, Kandadji, and Taoussa multipurpose dams); and (c) capacity building for the NBA and other water actors. The Climate Risk Assessment conducted by the NBA in 2015 revealed that the abovementioned infrastructure would be robust under different climate change scenarios. The infrastructure could potentially contribute to diminish the risks of floods and droughts, enabling minimum flows during the dry season, as well as augmenting the potential for hydropower, irrigation, and other water uses. This will bring benefits to rural livelihoods enhancing their food and water security, and decreasing the damages caused by floods and droughts in the past.

Similarly, under the platform of the NBA, Niger Basin countries also collaboratively developed the Investment Plan for the Strengthening of Resilience to Climate Change in the Niger River Basin (CRIP). The plan was presented at the UNFCCC COP21 in Paris to raise the profile of their climate adaptation needs. It consists of 246 carefully selected resilience-building investments, amounting to an estimated US$3.1 billion, from key regional and national plans. Each investment included in the plan was examined and vetted by member states through a comprehensive consultative process with multi-sectoral participation, strategically coupled with exercises to build local capacity. Collaborative resource mobilization through the CRIP is already attracting climate-related financing, with successful mobilization of a US$450 million investment.

4.3.2 Cooperation enables improved design, operation, and restoration of built and natural infrastructure, enhancing system robustness

Individual countries might not have the technical capacity or financing needed to develop critical infrastructure investments. Alternatively, historical legacies and emerging hydropolitics might block advancement of infrastructure even in cases where the economic rationale for developing such infrastructure is strong for all riparians involved. In these cases, riparian cooperation is crucial to overcome barriers and put in place resilience-building infrastructure. Further, riparian cooperation can drive improvement in the quality of cooperative infrastructure investments—through increased financial resources, pooled capacity, and greater accountability.

Cooperation is also critical for optimal operation of infrastructure and for equitable benefit sharing across stakeholders. Operation of infrastructure within a transboundary basin is interdependent, with the operation of upstream infrastructure having impacts downstream. Effective cooperation, joint operating rules, and shared information enable a coordinated response by infrastructure managers to climate variability, and where these are in place and supported by effective information, they can provide flexibility in response to changing climate and extreme events. Coordinated operation in transboundary basins supports integration and connectivity, as well as adaptation and even transformability to changing climate conditions.

Advanced models can also be used to optimize operation of infrastructure in a basin, such as coordination of a series of barrages or reservoirs, harmonization of irrigation withdrawals with upstream hydropower releases, and operation of reservoirs with appropriately characterized base- and peak-flows to help maintain ecosystem services downstream and in the delta. Coordinated operation of infrastructure can provide both adaptation and mitigation benefits as it can increase hydropower production potential, decrease water losses, optimize stakeholder withdrawals, and maintain the delta regions, and the climate risk reduction benefits they provide such as protection against storm surges, salt water intrusion, and land subsidence.

This need for cooperation extends to the management of ecological infrastructure systems. Functioning ecological infrastructure is increasingly being recognized as a cost-effective means of flow regulation and waste assimilation. Ecosystems tend to be auto-adaptive, integrated, and diverse, and so have many of the key attributes that provide robustness to changing climate. With the transboundary nature of ecosystem assets, cooperation is key to ensure their sustainability and enhanced functioning.

As highlighted above, in the absence of climate-relevant planning and operation of infrastructure, whether this is due to inappropriate information analysis, rigid institutions, or limited planning, the likelihood of sunk assets or at least suboptimal outcomes increases as climatic and hydrological conditions occur. Where these changes are dramatic and cannot be overcome, this may have consequences for the interests of the basin countries to continue cooperation.

Examining the evidence: Cooperation enables improved design, operation and restoration of built and natural infrastructure in the Nile and Zambezi Basins

Cooperative management of watershed and preservation of catchments help build resilience and sustainable development in the Nile and Zambezi Basins. Cooperative catchment preservation is crucial to ensure energy security and resilience in the Zambezi Basin. Cooperative catchment conservation in the Miombo Woodlands and the Barotse Flats in Zambia and Angola in the Upper Zambezi is critical for the long-term climate-resilient future operation of the downstream mainstream hydropower from Kariba, Batoka, and Cahora Bassa Dams. The impacts of the recent southern Africa drought on hydropower generation from Kariba Dam is believed to have been exacerbated by degradation of the upstream woodlands and wetlands in Zambia by people in search of fuelwood and livelihoods. The loss of beneficial highland ecosystems will be increasingly felt as the hydrology becomes more variable.

Similarly, integrated watershed management in Ethiopia has proven to provide benefits for people dependent on the land for their lives and livelihoods, as well as for populations living downstream in the floodplains in Sudan, and for hydraulic infrastructure in Sudan and Egypt. The Blue Nile, which meets the White Nile in Khartoum, takes with it 150–300 million tons of silt annually, clogging the irrigation systems in Gezira and reducing the live storage in Sudan's Roseires, Sennar, and Merowe Dams and Egypt's Aswan Dam, as well as exacerbating overbank floods due to increased sediment deposit. Deforestation in the Ethiopian highlands for energy and food security exacerbated the high rates of soil erosion. Actions undertaken in Ethiopia along the 3 I's—information (weather radar and hydromet systems to improve forecast, Geographic Information System [GIS] knowledge base, government and community silt monitoring, analytical tools for erosion modelling, basin atlases); institutions (capacity building including internship program, office and laboratory modernization, inter-basin study tours); investments (large investment programs, such as the Tana and Beles Integrated Water Resources Development Project that undertakes watershed management at scale through soil and water conservation, afforestation, small-scale irrigation, sustainable agricultural diversification and marketing, transport connectivity improvements, and other livelihood support activities)—improve climate resilience by increasing the capacity of the communities, encouraging adoption of improved sustainable farming practices, and improving forecasting, preparedness, and early warning systems to better manage rainfall variability and flood risks. Improved coordination among Ethiopia, Sudan, and Egypt is critical to capturing these transboundary benefits.

Cooperative rehabilitation of the Kariba Dam in the Zambezi Basin will allow this critical infrastructure to continue much needed hydropower production while ensuring safety of downstream populations. Built over 50 years ago, the Kariba Dam is an engineering marvel that has created the world's largest manmade reservoir, storing 181 billion cubic meters of water in Lake Kariba. This storage capacity is critical for the Zambezi, which is projected to experience increased aridity and more frequent and prolonged droughts due to climate change. With an installed capacity of 1,830 MW, the Kariba Dam provides approximately 50 percent of electricity consumed in Zambia and Zimbabwe. With a drier future, it will be even more critical to ensure safe operation of the dam to provide subsistence farmers alternative economic opportunities.

Collaboration between Zimbabwe and Zambia facilitated by the ZRA has successfully garnered US$295 million in support of four funding agencies to conduct a basin-wide dam break analysis and undertake subsequent maintenance works on the Kariba Dam. Through rehabilitation of this important infrastructure, the riparian countries hope to safeguard downstream communities while continuing to generate an affordable, reliable supply of clean hydropower to foster sustainable economic growth. Going forward, along with infrastructure development, states should build in the institutional and financial model to ensure sustained maintenance of infrastructure. Shared institutions, including River Basin Organizations (RBOs), should help states agree on sustainable joint planning for the basin.

While cooperation may enable additional sources of finance, these cases indicate that this requires the appropriate institutional arrangements between governments and transboundary organizations to ensure an acceptable investment environment and build confidence in the implementation process, and thereby to leverage the climate, development, or commercial finance required to build resilience.

5 Transboundary Water Management Systems Provide the Platform for Resilient Economies and Societies

KEY MESSAGES

- Resilience in water management systems built through transboundary cooperation around information systems, institutional frameworks, and infrastructure provide economic systems, livelihoods, and ecosystems the flexibility, resources, and capacity necessary to build overall systemic resilience. Systemic resilience allows current systems to adapt, reorganize, and evolve into new sustainable states that are more suited to a changing climate and are better prepared for further changes.
- As evidenced in transboundary basins in Africa, resilience in water management systems enables shifts in social and economic activities toward 'future-oriented' behavior at the levels of communities, cities, provinces, and across international borders, to build systemic resilience.
- Shifts toward more resilient economic and social activities create adaptive pathways that provide positive feedback into climate-resilient developmental trajectories by catalyzing socioeconomic development by ensuring reliable water supply and harnessing subsequent productive benefits and avoiding potential losses in socioeconomic development by mitigating climate-related water risks including floods, droughts, and disease.

The preceding chapter has made the argument that cooperative efforts that build shared information, flexible institutions, and robust infrastructure around transboundary waters foster climate resilience by enabling preparedness, diversity-redundancy, integration-connectedness, and robustness. This enables transboundary water resources systems to *absorb current and future climate-related shocks and stresses and maintain function in the face of it*. However, the second aspect of resilience requires systems to *adapt, reorganize, and evolve into new sustainable states that are more suited to a changing climate and are better prepared for further changes, that is, build systemic resilience*. This systemic resilience relates to the degree to which water-related cooperation provides for **adaptability** of the hydro-economic systems and the degree to which the resulting socioeconomic development enables **transformability** of the entire system to more resilient states.

For a system to adapt and transform, it is necessary for the hydro-social-economic system to have an improved alternative state to shift into that is more adapted to the new climate state, as well as the ability to shift to one of those new states. In other words, there must be (a) flexibility in the system, which requires that the appropriate options have not been previously foreclosed by prior decisions—a fundamental element of climate-robust decision making, supported by diversity and integration; and (b) resources and capacity that enable the implementation of the necessary shift to a more climate-resilient state—a fundamental aspect of a climate-robust development trajectory that should be enabled by climate-resilient water information, institutions, and infrastructure.

The thesis of this chapter is therefore that transboundary cooperation builds shared trusted information systems, enables flexible institutions, and advances sustainable and robust infrastructure, which enable systemic resilience through broader, efficient, equitable, and sustainable development outcomes that go beyond the water sector. Systemic resilience enables shifts in social or economic activities or behaviors that are needed to respond to the pressures of significant changes in climate. Such shifts happen at a range of scales, from the households and community level, to cities and provinces, to countries and economic regions.

Countries and regions that are able to leverage development outcomes to build systemic resilience are better able to withstand climate shocks and stresses to enable more efficient, equitable and sustainable socioeconomic development in the long term, even under a significantly changing climate. Adapting the framing by Sadoff et al. (2015), we posit that systemic resilience can gradually be built by mobilizing resilience-building water management systems to create adaptive pathways that provide positive feedback into climate-resilient developmental trajectories via:

1. catalyzing socioeconomic development by ensuring reliable water supply and harnessing subsequent productive benefits;
2. avoiding potential losses in socioeconomic development by mitigating climate-related water risks including floods, droughts, and disease.

Evidence from the cases presented in the previous chapter are used in the following discussion to support these two distinct and necessary contributions to systemic resilience.

5.1 Cooperative Water Management Catalyzes Socioeconomic Development

Transboundary cooperation catalyzes economic growth through optimally developing water resources; it does so by enabling the most appropriate options, by efficiently allocating water resources and potentially leveraging comparative advantage between countries and sectors, as well as by reducing the economic impacts of climate disasters between and within countries. The growth of developing economies usually goes hand in hand with a trend of economic diversification. Globally, economic growth has led to a growth of the secondary and tertiary sectors of the economy. In Africa, where most state economies are heavily based on the primary sector, a shift toward more secondary and tertiary sector activities would lead to a diversification of the economy. Diversification of the economy may also be used to decouple economic production from water dependency and build capital to adapt to future changes, thereby building greater resilience.

Transboundary information, institutional, and infrastructure cooperation also results in improved ecosystems and livelihood security for communities within transboundary basins, both of which can build the resilience of those groups that are typically most vulnerable to climate change. This improved resilience enables households and communities to accumulate local resources despite the shocks and stresses of climate variability, which in turn enables them to auto-adapt to a changing climate. This adaptability of households/communities is enhanced where the institutions and infrastructure themselves are flexible and robust to changing climate.

Furthermore, if the information, institutional, and infrastructure systems have been implemented in a manner that is robust to climate change, these systems increase the flexibility levels in the management of water, thereby allowing for more adaptability. This virtuous cycle helps economies to withstand fundamental climate shifts and contributes to further opportunities to invest in systems which deliver growth and resilience benefits.

Examining the evidence: Cooperative water management catalyzes socioeconomic development in Gauteng Province in South Africa and SADC capital cities, the Zambezi Basin, and the Eastern Nile Basin

In the Gauteng Province in South Africa, as well as in other SADC capital cities, robust transboundary water supply infrastructure enables advancing economic development and building systemic resilience. Economic hubs—cities or provinces—are key to the socioeconomic development of the country they are in, for the high proportion of GDP they create. They can also play a key role in the development of a broader region, for their high demand of goods and services to their hinterland. In other words, these economic hubs are part of the broader regional economic fabric and typically have positive consequences for regional economies.

Over the past century, Johannesburg, in the Gauteng Province, has evolved from a primarily mining center to a diversified manufacturing and services economy and a major African economic hub. Despite being in an arid region on a watershed between the Orange and Limpopo Rivers, Johannesburg's growth has been enabled by an increasingly complex water system. Since the 1980s Gauteng Province has been supplied by a water transfer system that links several rivers in South Africa and Lesotho. These rivers are in different climate regions, which helps diversify climate risks to the water supply of Gauteng, and thus makes the region's economy less vulnerable to climate shocks and stresses. The diversity, integration, and robustness of water management makes for a system that is resilient to climate change, which will ensure its future development trajectory and an economy that is increasingly decoupled from water dependency. While the 2015–2016 drought was significant, Gauteng was spared the worst of its negative effects compared to the rest of the country (AgriSA 2016). The flexibility of the water system and the resources that have been developed will help ensure the continued resilience of the region, regardless of the uncertain climate future (see National Treasury analysis, Section 3.3.1.). The prosperity of the Gauteng region benefits not only South Africa, but reaches the wider southern African region.

Major economic hubs have specific domestic and industrial water requirements. Where these economic hubs are dependent upon transboundary basins, the need to cooperate is high. The need for cooperation is particularly strong where the transboundary basin is expected to be impacted by decreasing water availability or increasing variability. Climate change presents risks to the water supply of many African cities, from Maputo and Windhoek to Cairo and Accra. In Maputo for example, the main water supply is the Umbeluzi River, which rises in Swaziland. As there is a significant chance that rainfall will decrease in these areas under a changing climate, future supplies are expected to be drawn from the Incomati River, which rises and is extensively used in South Africa. In the long run, safeguarding Maputo's water supply will be dependent on continued rainfall in Swaziland and South Africa; it will also depend on the capacity of Maputo to ensure that upstream states will not deplete the resource, so that levels of water crossing the border will be sufficient for Mozambique. The climate resilience of Maputo, and more broadly of southern Mozambique, is therefore directly dependent upon the ability of the countries to cooperate and effectively implement agreements that are adaptable to changing climate. Similarly, future water supply to Gaborone is expected to be from the Orange River in Lesotho or the Zambezi River, while Windhoek water transfer is being planned from the Okavango River. Continued socioeconomic development of these capital cities therefore depends on the ability of their countries to manage institutional and infrastructural cooperation, together with the resources to afford these costly schemes.

In the Zambezi River Basin, cooperation strengthens regional resilience and adaptability to climate shocks and stresses, as illustrated by the impact of Southern African Power Pool (SAPP) on regional energy security. Beyond supporting economic growth, transboundary cooperation helps strengthen regional systemic resilience through building resilience in other sectors, such as energy. The cooperation of southern African states in energy production through the SAPP helps build energy security in the region. Energy security is key to systemic resilience as energy underpins the development of these economies. Building connected power pools through the most efficient and cost-effective generation options helps build regional energy security. Part of the diversified energy mix of the SAPP is hydropower and thermal plants, with increasing wind and solar. Hydropower is an important enabler of more variable renewable energy because of its rapid response and storage capabilities. Most hydropower plants in southern Africa are based on transboundary basins, and thus depend upon transboundary water flows. The collaboration of southern African states through the SAPP should increase the diversity and levels of productive capacity of energy, but is dependent upon intercountry trust and cooperation that is fostered through transboundary initiatives.

The SAPP aims to help its members and the whole southern African region to become more resilient, by offering more diversity and redundancy in the energy supply and hydropower production. This is most needed in the Zambezi region, which currently lacks diversity and redundancy in energy production systems, and has thus been facing energy shortages. Only 30 percent (16,000 MW) of Zambezi's potential hydropower production capacity (16,000 MW) has been developed (Spalding-Fecher, Joyceb, and Win 2017); ample opportunity therefore exists to address unmet needs, while building in the needed redundancy into the system. Despite the intergovernmental memorandum of understanding included in each power purchase agreement (Economic Consulting Associates 2009), water shortages have led producing states such as Zambia to favor national energy demands and to deny energy supply to neighboring states. Redundancy in the system should reverse this trend and enable the development of least-cost energy supply solutions across the region. Transboundary initiatives such as Batoka Gorge hydropower scheme add to the resilience of the SAPP.

Institutional cooperation on water can help improve livelihoods of communities by enabling investments at the community level, as illustrated by cooperation between Zimbabwe and Mozambique on the Pungwe and Save Rivers. The cooperation between the ZINWA-Save—the Zimbabwe National Water Authority (ZINWA) managing water resources in the river system of Save—and the Mozambican ARA-Centro—the main Mozambican institution responsible for the planning and management of the water sector—has been important to implement joint local livelihoods projects. The two institutions have worked together under the Pungwe Project, a project aimed at strengthening the capacity of key basin IWRM institutions to efficiently, effectively, and sustainably fulfil their defined roles and responsibility. Ultimately, the project aims at strengthening and expanding stakeholder participation in Integrated Water Resources Management and Development (IWRM&D) in the Pungwe River Basin, as well as at ensuring appropriate, efficient, effective, and sustainable technical systems and capacities for the collection, monitoring, management, and communication of water resources data. Finally, the project has mobilized resources for sustainable, poverty-oriented, water-related development investments in the Pungwe Basin through establishment of a Pungwe Basin Pre-Investment Facility and launching of the Pungwe Basin Initiative. Helping local communities strengthen their water resilience enables them to improve their socioeconomic status and thus provides systemic livelihoods resilience through providing community and household resources that may be channeled into responding to future climate changes. Transboundary cooperation can therefore be used to leverage finance into sustainable livelihoods resilience initiatives in the basin, that may otherwise not have occurred.

Cooperative exploration of multiple benefits, and establishing mechanisms to distribute these benefits equitably, can make critical storage investments an attractive option for riparian countries in the Eastern Nile. The Eastern Nile has many natural sites well suited to create storage reservoirs vital for managing variability, at relatively low costs and with relatively little environmental and social disruption.

To overcome the challenge of downstream countries perceiving storage as consumptive use (due to decreased control over timing of flow), riparians have an opportunity to evaluate a multitude of benefits such as hydropower generation, small-scale irrigation, water supply, flood control, sediment control, and upstream catchment rehabilitation, and to work out cooperative operational mechanisms to ensure that benefits are equitably distributed across all riparians.

Managing these multiple uses will involve complex inter-sectoral trade-offs, which in this case, will be further complicated by the fact that multiple countries are involved. For example, reservoir levels must be kept low enough to provide flood retention capacity when the heavy rains come in July, while at the same time full enough to conserve water in the event of a drought. Similarly, water releases for power generation must be weighed against requirements for irrigation, all in line with system requirements such as environmental flows. Eastern Nile countries have tasked the NBI with developing a set of guiding principles that will help establish cooperative use of reservoirs that exist in cascade in the region, to further improve the environment for implementing much needed storage investments.

5.2 Cooperative Water Management Mitigates Socioeconomic Risks

Transboundary cooperation mitigates the risks associated with extreme events, particularly floods and droughts; it does so by utilizing early warning systems built on information and institutional communication, as well as jointly planned and developed flood or drought management infrastructure and systems. This in turn avoids the worst human, infrastructure, and economic losses associated with these extreme events across river basins and countries. In most regions in Africa, extreme events are expected to become more frequent, more intense, of greater duration, or at a different time. Any of these consequences pose significant costs to the affected country's society and economy.

Population settlements and economic activities typically flourish along rivers and as economies develop and populations grow, the people and value at risk from flooding typically increases. Unmanaged flood risk has dramatic consequences for downstream business and communities, as well as imposing massive economic costs through lost production and trade, and in repairing households and infrastructure. Major floods reduce economic (GDP) growth in the year during which they occur. Impacts on the most marginal people's livelihoods is similarly devastating, with impacted households being trapped in a cycle of poverty as resources are eroded through repetitive flood events.

Prolonged droughts also have devastating effects on economies, particularly those dependent on agriculture or hydropower, which is the case in most African countries. Cooperative transboundary water information and infrastructure systems can ameliorate the worst impacts of droughts, and thereby reduce the typically significant losses that these countries' GDP suffer. Similarly, where droughts are predicted and managed, the impacts on the most vulnerable rural communities and households can be reduced, so that their meagre resources are not as severely eroded.

Furthermore, if the information, institutional, and infrastructure systems have been implemented in a manner that is robust to the extremes of a changing climate, they allow for more flexibility and adaptability to potential future increases in these extremes. By breaking the vicious cycle of repetitive extremes (often alternating between floods and droughts) impacting economies and households, the avoided costs can instead be channeled into investment and resources that contribute to delivering growth and resilience benefits and adaptation to fundamental climate shifts.

Examining the evidence: Cooperative water management mitigates socioeconomic risks in the Limpopo Basin, Nile Basin and the Niger Inner Delta

Transboundary cooperation reduces the economic impact of climate shocks on water resources and the economy. The damage to economic infrastructure and production associated with flooding often has profound impacts on economic growth in affected countries and districts. In countries vulnerable to climate shocks and stresses, economic growth trajectories thus fluctuate as a result of these external impacts. This is both because of the direct costs of weather hazards (income and asset losses for farmers, food supply shortages and price spikes, generalized decline in agricultural productivity, as well as damaged transport, irrigation, water supply, urban drainage, sanitation, and private assets, further disrupting private sector activities), and longer term costs, including those emanating from disease outbreaks (waterborne diseases and so on). The post-shock public expenditure represents an opportunity cost, as the financial resources utilized to meet reconstruction needs could have otherwise—in a most resilient case scenario—been used as investments for further growth.

By helping to reach agreements that benefit all riparian states, transboundary cooperation can help set up mechanisms to provide disadvantaged riparians with opportunities and resources to build capacity to absorb climate shocks and stresses, and to adapt to changing climate development stresses. Harmonizing development levels in a region is often key to the stability of that region—in terms of regulating water, energy, and food security levels regionally, as well as to manage migration flux. In a changing climate, regional stability provides an important condition for resilience of the countries within the region.

The case of the Limpopo Basin illustrated the interdependencies of the riparian states' economies, and the growing needs for cooperation to distribute risks and costs in a changing climate. The river flows through Botswana, South Africa, and Zimbabwe before reaching Mozambique, the downstream state. Intensive water use in the upstream countries, especially South Africa and Zimbabwe, results in a reduced flow within the Mozambican borders, drying up completely for 3–4 months in a normal year, and up to 8 months in a dry year (FAO n.d.). Conversely, in wet times, the Mozambican Gaza Province is at risk of floods due to upstream dams' operating rules and climate impacts upstream. Exposure to climate shocks and stresses is thus high, and it is expected to increase with climate change. While climate variability has already impacted the southern Mozambique and the Mozambican Limpopo Basin, climate change is expected to exacerbate such impacts. Moreover, the adaptive capacity of the Mozambican population is low because of high poverty rates and lack of infrastructure (LIMCOM 2013). For economic development to take place equally in the Limpopo transboundary basin, and particularly in the Mozambican part of the basin, it is critical that stable and secure water supply is provided to avoid droughts. Information sharing to prevent and mitigate the impact of foods will also be key. Ensuring water and information flows will require cooperation and planning with the upper riparian countries, as the water availability in the region is directly dictated by the activities upstream.

Numbers for Mozambique, where an estimated 58 percent of the population of Mozambique is at risk of water-related hazards, are striking. In the country, extreme climate-related events, in particular floods and coastal cyclones, have devastating effects on the economy. These events affect agriculture, electricity generation, mining, and transport and communications. Mozambique loses an approximate 1.1 percent of GDP annually due to weather hazards. Such economic losses represented US$1.75 billion between 1980 and 2003, and if no major change in policies is observed, it is expected that climate change will cause economic damages between US$2.3 to US$7.4 billion during the period 2003–2050 (World Bank 2014). Such an impact on the GDP undermines the country's development and economic progress. Better policies can help address these risks. Climate-related risks can be mitigated by improving weather forecasting, early warning systems, and flood management mechanisms, as well as by helping smallholder farmers to introduce climate-resilient agricultural techniques.

Such preventive and reactive systems are particularly important in regions where rainfall patterns are likely to become more intense with increased flood risk under changing climate. Cooperation to implement these mitigation options is also key, especially for downstream states in transboundary basins. Mozambique is again a good example. As discussed, Mozambique is highly exposed to climate hazards. This exposure can be partly explained by the geographic position of the country, sharing nine river basins with neighboring countries (GFDRR 2014); Mozambique is the lower riparian for nine major international river systems that drain massive areas of southeastern Africa. Therefore, Mozambique needs to manage the effects of rainfall in areas that fall outside of the country's own catchments. An estimated 50 percent of water in Mozambique's rivers comes from outside of the country. This is a risk in terms of both droughts and floods. Flooding in Mozambique has received significant attention, as floods have occurred every two to three years along the major rivers of Incomati, Limpopo, Save, Buzi, Pungue, Zambezi, and Licungo. Areas most heavily hit include that of the Limpopo River Basin and the Northern Province of Nampula, both of which are impacted by rainfall outside of Mozambique's borders.

Due to its limited financial resources, it is difficult for Mozambique to build resilience against climate-related disasters risks. This creates a vicious cycle, as Mozambique's economic development is damaged by the impacts of major floods. For instance, in 2000, Mozambique's GDP fell from a forecasted 7 percent to 1.5 percent (World Bank 2014). Despite limited resources, Mozambique has policies and structures in place for domestic flood management. However, it cannot address its water-related climate challenges alone, since weather events outside the country influence the local situation so heavily. Regional cooperation is therefore critical. The Southern African Regional Climate Outlook Forum (SARCOF)—a transboundary institution mandated to facilitate information exchange and interaction among forecasters, decision makers, and climate information users in the 14 SADC member states—plays a crucial role in providing information for the Mozambique National Institute of Meteorology flood forecast models. In Mozambique, as in other downstream states, cooperation is key to prevent and manage climate-related shocks and stresses on water resources. Cooperation is thus ultimately key to the stability of Mozambique's economic growth. Cooperative actions to minimize the negative effects of extreme climatic events on the Mozambican economy contribute to stabilizing and strengthening the country's economic growth.

Transboundary cooperation around the 3 I's enables communities to plan, be alerted, and react after a disaster. In the context of shared transboundary basins, cooperation is often required to create an effective early warning and disaster management system that limits the loss of life and local community livelihoods associated with extreme events. To be effective, such a system should protect communities, including the most vulnerable ones; very often, poor communities in both rural and urban areas are highly exposed to disasters' impacts.

To protect such communities, support by the authorities is key. A case study in Malawi showed that, while an instantaneous support reaction by the authorities can spare households any costs related to a disaster, a four-month delay in disaster management interventions can increase the costs of a drought to households to US$50 per household, and further delays (six to nine months) can increase costs to about US$1,300. This rapid cost increase is explained by irreversible impacts of disasters on the development of children, and by 'distress sales' of an asset, in particular livestock (Hallegatte et al. 2016).

However, this support by relevant authorities often needs to be informed by transboundary systems. Successful examples of such systems include the flood warning system established by Ethiopia, Sudan, and South Sudan in the Nile Basin, a system which communicates with around 350,000 people in high-flood risk areas. They receive early warning messages during the flood season as well as daily alerts; a further 1.7 million people indirectly benefit from this service, and are better able to reduce their risk of flood devastation.

Among the beneficiaries are the subsistence farmers and livestock pastoralists who are at highest risk; the system helps them make informed decisions to plan the timing of cropping for the season, avert loss of lives and livestock, reduce property damage, and minimize disruption of productive activities, as well as plan potential temporary migration.

Transboundary cooperation results in improved livelihood security for communities within transboundary basins by reducing instability and migration. Livelihood resilience is very much associated with stability, while vulnerability is correlated with mobility. Climate-related migration is usually motivated by a search of economic opportunities when traditional livelihoods are under climate-related threat, or takes place as a result of a violent or series of repeated extreme climate events or climate disasters. People with reliable rural livelihoods that are resilient to climate variability and change are less likely to move to urban areas or to other countries, as their life, health, livelihoods, and property are not under obvious threat. Increased resilience thus should reduce the social challenges of significant inter-country migration and the resulting pressures on already stressed peri-urban areas of cities. This is well exemplified by the situation in the Lake Chad Basin.

The banks and islands of Lake Chad provide a functioning and thriving ecosystem upon which two million people rely. Agriculture around the lake provides food security to 13 million inhabitants and two metropolitan centers. The agricultural scene of the lake is dominated by subsistence farming, and the crops are typically rain-fed and harvested by hand. In light of growing water scarcity, farmers have begun to divert water out of lakes and rivers into cultivation plots, such as those along the Komadugou River. In general, years without beneficial flooding are associated with a movement of population toward the south, a movement motivated by a search for better livelihoods. In addition to climate-induced migration, the Lake Chad Basin experiences migration due to the current humanitarian and security crisis it is facing under the Boko Haram threat.

Migration flows put a strain on the area and communities hosting them, especially when these were previously resource-strained. This can reduce the resilience of host communities. Increasing the climate-related and overall security of communities in the basin is thus an important task for riparian governments. Maintaining stable rural livelihoods in the basin, but also protecting the ecosystems upon which local communities rely (for the ecological goods and services they provide) is key. For that, building the adaptive capacity and thus resilience of both communities and the natural ecosystem is crucial to prevent otherwise avoidable migration flows.

Efforts to build adaptive capacity can be led both at the national and international levels. Local action depends on basin-wide information on the evolution of threats, including climate and resource-related threats to livelihoods and natural ecosystems. Moreover, pooling resources is particularly important for the riparian states of the Lake Chad Basin, which are all considered as fragile states. Institutions are weak and adapted infrastructure inexistent; the status quo is further affected by the actions of armed groups in the region described above. The usefulness for riparian states to work hand in hand through transboundary institutions has been shown. The LCBC has been serving as a platform for countries to combine efforts in tackling regional security and migration concerns. Indeed, it was at the LCBC Extraordinary Summit in Niger that a Multinational Joint Task Force was formed. This Task Force helps to facilitate cross-border operational coordination and coordinate intelligence and joint planning. It is expected that this Task Force will take steps leading to strengthen the resilience of Lake Chad Basin communities.

Transboundary cooperation results in improved natural-resource-based systems. Natural catchment covers and functioning aquatic ecosystems that provide flow attenuation, waste (water quality) assimilation, and erosion retention are critical to providing resilience for economic activities against upstream climatic or development stresses and shocks. Where the water resources for these ecosystems or the basin's critical ecosystems themselves are located in upstream countries, the need for cooperation that considers climate implications is critical to their sustained functioning. These systems typically provide inherent resilience to climate variability, but may undergo state shifts after which they provide reduced services, once pushed beyond a threshold, either through prolonged development-climate stress or multiple shocks.

For instance, cooperation through the 3 I's will maintain the natural characteristics of the NID and the environmental benefits that the wetland brings to the basin. The NID constitutes important natural infrastructure for mitigating the impacts of climate variability, maintaining minimum flows and protecting downstream areas from flooding. During very wet years, only about 25 percent of the upstream flood maximum reaches downstream of the NID-Timbuktu (while this fraction is 55 percent in very dry years). This illustrates the important role of the NID in natural flood management and flood control for the region. Similarly, water losses due to evapotranspiration and infiltration from the flooded areas in the NID, range from 30 percent of the Inner Delta's annual inflow under very dry conditions to 55 percent under very wet conditions. In very dry years, the fraction of the total annual flow passing through the NID is thus 25 percent higher than in very wet years, demonstrating the flow-regulating function of the NID.

6 Conclusions: Transboundary Actions That Build Climate Resilience

Water resources are a primary channel through which economic systems, livelihoods, and ecosystems in Africa experience the impacts of climate change. Strengthening water-resource-related information systems, institutional frameworks, and infrastructure offers a critical means through which countries and communities can build resilience. Given that most of Africa's water resources, both above surface and below ground, are transboundary, significant action around the 3 I's will be need to be regional, and therefore cooperative in nature. Cooperative action could take different forms, depending on the basin context, ranging from regional harmonization of nationally implemented action to jointly implemented investments, or collaborating to prioritize a portfolio of projects across different sections in a basin that are collectively cost-effective and enable equitable sharing of benefits among different riparians.

Because of cooperative action, transboundary water management systems can improve preparedness to manage and cope with change and shocks; include greater redundancy to ensure continuation of functionality; increase sectoral and geographic integration to allow for optimization and harness benefits of scale; and emerge overall more robust to withstand change and shocks. These actions also lay the foundation required for systems to adapt, reorganize, and evolve into new sustainable states that are more suited to a changing climate and are better prepared for further changes, thereby building systemic resilience. The shift toward a more 'future-oriented' state allows countries to further overcome spatial and temporal fragmentation and to make robust cooperative investments in the development of their common water resource. This future orientation allows countries to prepare for a changing and uncertain future that will be impacted by climate change, considering opportunities to build resilience at every juncture in the decision-making process.

Key recommendations. Well-designed, targeted investment in the 3 I's is needed to achieve climate resilience in economic, livelihoods, and ecosystems, which in turn underpin gains in systemic resilience. Recommendations to guide climate-resilience-building water-resource investments include the following:

- Investment in transboundary information management and institutional strengthening and cross-border harmonization create the enabling environment for robust infrastructure that is critical for managing increasing variability and more frequent and more intense extreme events. Cooperative design and operation of infrastructure, particularly when a basin perspective is adopted, avoids locking riparian states into pathways that might become obsolete in a dynamic world.
- Multi-sectoral investments prepared and implemented from a regional perspective provide opportunities for optimizing water use and expanding benefits into beyond-water areas, increasing the likelihood of sustained cooperation and sustainable resilience outcomes. For example, sustainability of resilience outcomes from built storage infrastructure can be improved through accompanying investments in managing watersheds, maintaining associated ecosystem services, and strengthening sustainable livelihoods; influencing policy to encourage cultivation of water-efficient crops, improve irrigation efficiency, adopt conjunctive use of surface and groundwater, and establishing monitoring mechanisms all across can greatly expand the domains of resilience outcomes.
- Resilience building under uncertainty requires institutional arrangements that are flexible and have the capacity to learn and adapt to changes in the hydrological, human, economic, and natural environments. For example, a percentage-based water allocation model that respects minimum flows, or regional dam safety regulations

that specify a framework for coordinated real-time forecasting, monitoring, and communication across a cascade, can help these institutions adapt to climate conditions, while enabling riparian countries to achieve their objectives.
- Investment in cooperative monitoring and early warning systems is critical for managing risks from floods and droughts and allowing riparian states to build knowledge that is crucial for longer term resilience planning in the basin.
- Proactive adoption of a climate lens early in planning for shared information systems, institutional frameworks, and infrastructure is necessary not only to ensure that climate considerations are effectively addressed to adequately account for climate change, but also to attract buy-in from climate financiers.

Operationalizing cooperative transboundary action. African states have demonstrated how cooperative water resources investments harnessing the principles described above deliver water-related outcomes that contribute to growth and poverty alleviation. They have also shown how outcomes beyond water resources, such as peace and security dividends, contribute to the avoidance of conflict and promotion of overall regional stability. Together, this introduces a multiplier effect in terms of economic growth and resilience (World Bank 2017). While there are many examples of success, there are even more opportunities for future cooperation to reap a range of growth and resilience benefits. Even after countries perceive that the benefits of cooperation outweigh the risks, operationalizing transboundary water resources management and development in a way that builds resilience remains a challenge. This section provides observations on implementing cooperative processes in African countries and how development partners can support strengthened water resources management and development that ultimately builds climate resilience.

1. **A combination of poverty-targeted and region-wide transboundary water interventions advance the goals of African governments to reduce poverty and accelerate economic growth, while building climate resilience.** African governments allocate their resources to addressing poverty and accelerating economic growth. Transboundary water-related support for broad-based water resource interventions can take the form of pro-poor, large-scale multipurpose river basin development projects along with poverty-targeted interventions like watershed management which directly work with poor farmers on rehabilitation of degraded catchments and improving livelihoods sustainability. Combination of large-scale and targeted actions can reduce vulnerabilities in economic and livelihoods systems, meeting the needs of a wide range of stakeholders and ultimately advancing systemic resilience.
2. **Management of climate change vulnerabilities common to multiple basin countries is an increasingly important and compelling driver for cooperative action.** Climate change raises the stakes of non-cooperation by intensifying existing risks in transboundary basins. Dialogue, data, analysis, and knowledge help countries understand the impacts of climate change and how managing their subsequent vulnerabilities can be an incentive for cooperative action.
3. **Balancing institutional strengthening with improving and advancing investments meets a variety of stakeholder needs, while continuing to build climate resilience and water security.** The primary drivers for cooperation among countries are investments that harness water's productive potential and contribute toward their national development objectives. The successful implementation of investments, however, depends upon strong institutions at regional and national levels that are capable of integrating a range of needs and demands and structuring investment portfolios based on stakeholder dialogue and sound hydrological and climate data. Balancing actions that strengthen institutions and work to advance investments enables countries to progress toward their development and resilience goals.
4. **Institution building is a long-term process, and can accelerate or lapse around specific issues; progress is made through systematic and opportunistic action.** Institution building requires a long-term political, technical, and financial commitment to cooperative processes. Country and development partners' commitment to cooperative processes, however, changes with time, and is driven by perceptions of risks and opportunities. Perceptions of risk are shaped by changing realities within and around the basin. To address this challenge of shifting perception, countries and partners must continually communicate on how the benefits of cooperation exceed associated costs and strive to develop mechanisms that equitably distribute benefits.

Analytical work that evidences that net benefits of cooperation are greater than the net benefits of noncooperation, and illustrates that these net benefits can be distributed in a way that all stakeholders perceive to be fair, can establish the pivot needed for riparians to embark on a cooperative development trajectory. The need to jointly address the challenges of climate change provides an additional argument for cooperation to lay the platform for future action.

5. **Equally, opportunities for useful cooperation that rise out of a specific situation or relationship should not be overlooked.** Various examples across Africa demonstrate that joint or multi-stakeholder cooperation is often derived from unique relationships among technical or political counterparts. Often, specific extreme events such as droughts or floods can motivate action.
6. **Cooperative processes and solutions must be tailored to the region-specific growth, livelihoods, and resilience challenges.** Climate impacts vary across Africa as to required sectoral investments, livelihoods systems, and development challenges. The focus, nature, and scope of cooperative processes intended to advance resilience and growth must be tailored to the specific reality of each basin and sub-basin.
7. **Targeted analysis and process-focused support are essential for increasing the understanding of resilience gains derived from cooperative action and reducing the perceptions of risks associated with cooperative action.** Designated resources, technical assistance, and credibility of a convening group or facility is often required to inform, persuade, and motivate transboundary-scale action required to build adaptive capacity and resilience. (See Subramanian, Brown, and Wolf 2012 for further characterization of actions which help reduce perception of risk.)
8. **Transboundary investments should be embedded in a broader set of regional integration actions oriented toward stability, social development, and resilience.** Interconnected, efficient, diversified, equitable, and sustainable economies (dependent upon efficient, equitable, and sustainable transboundary water resources) are more resilient than those that are not. Transboundary water cooperation overcomes conflict, creates stability, and reduces eco-migration for social development in both rural and urban areas. Joint water-related actions between countries promote trade and stability, upon which sustainable growth and social development can be created. Diversified and integrated economies across climate zones hedge against localized climate (and development) shocks and stresses. Stable social and economic systems are required to build the economic resources and social capital to withstand climate shocks and stresses.
9. **Climate adaptation finance mechanisms should promote transboundary water projects that build climate resilience.** The establishment of viable and appropriate cooperative transboundary institutions enables investment and access to diverse sources of financing. This framework outlines how transboundary cooperation leading to robust water information, infrastructure, and institutions build climate resilience and shows the evidence for why investments in these important areas should leverage climate adaptation finance.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A Economies, Livelihoods, and Ecosystems Depend on Water and Are Vulnerable to Climate Impacts

The vulnerability of a system to climate impacts includes its exposure[3] to climate change and variability (external dimension), but also its sensitivity to these factors and its adaptive capacity (internal dimension) (IPCC 2008). Vulnerability represents the propensity or predisposition to be adversely affected, and so it is a characteristic that influences the magnitude of impact (IPCC 2012). This framework identifies thee major interlinked systems that experience vulnerabilities to water-related climate impacts: economic systems, rural livelihoods, and ecosystems.

1. Vulnerabilities in Economic Systems

Economic systems are vulnerable to climate impacts on water resources because of their inherent reliance on sufficient quality and quantity of available water. Large-scale economic systems are also vulnerable to the destructive powers of climate-related shocks such as drought, flood, and other hazards. It has been estimated that water scarcity induced by climate change could lead to 6–14 percent decline in growth rates in some regions of the world, which do not manage climate change adequately (Sadoff, Borgomeo, and de Waal 2017) Climate-related economic downturn has further consequences on the demography and stability of socioeconomic systems. For example, there have been cases where economic growth has been impaired by rainfall patterns; episodes of droughts and floods have generated waves of migration and spikes of violence (Sadoff, Borgomeo, and de Waal 2017).

In Africa, vulnerabilities of energy, agriculture, industry, municipal supply, and navigation sectors to climate-related impacts on water resources share several commonalities, but are manifested uniquely in each sector. These vulnerabilities are described in more detail below.

Energy

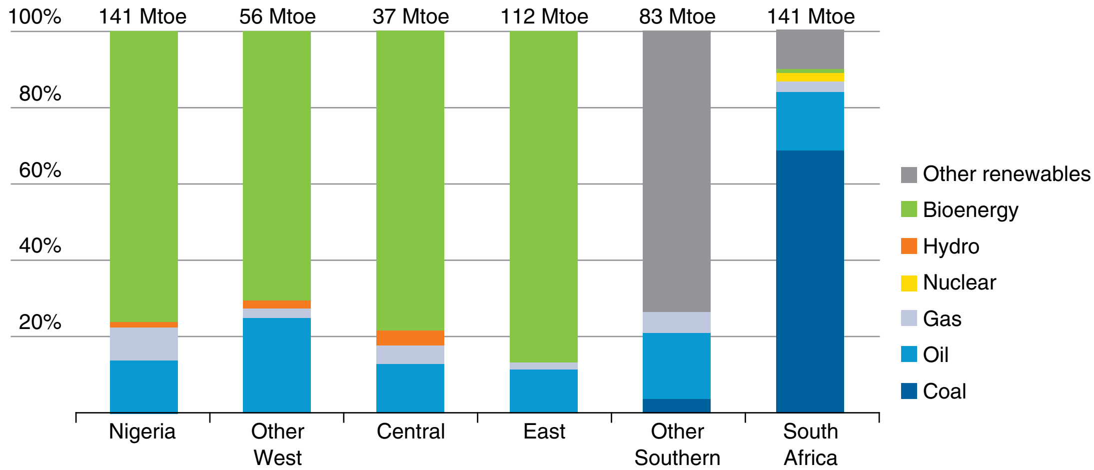
Hydropower today accounts for one-fifth of Africa's electricity supply, but at present, only a tenth of the continent's hydropower potential has been utilized (International Energy Agency 2014). Its tremendous untapped potential makes hydropower key to increasing electrification of Africa, and potentially substituting the continent's reliance on bioenergy and coal captured in Figure A1, which lend to intensification of global warming.

Through its impact on water resources, climate change will potentially affect hydropower in Africa in a number of ways. Increased aridity, increased temperatures, and more frequent and prolonged drought all lead to short- or long-term reduction in stream flows, decreasing the amount of power generated. This translates into economic costs both through sunken infrastructure costs, which are considerably large in the case of hydropower generation and transmission infrastructure, as well as through foregone benefits from economic activities intended to be driven by hydropower. Increased temperatures can lead to the proliferation of invasive vegetation such as water hyacinth, which can block and damage hydropower turbines. These changes can lead to decreased production or increased maintenance costs of hydropower infrastructure (Water Research Commission 2009).

More intense and more frequent rains, on the other hand, can increase flood incidents and raise flood peaks, challenging existing dam design and operating rules and necessitating increased attention to dam safety. Increased rainfall severity and frequency can also result in increased sediment load from steeper catchment areas, causing damage to electromechanical equipment in hydropower generation schemes which can severely reduce production

3 Exposure can also be defined as the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.

FIGURE A1 Primary energy mix by subregion in Sub-Saharan Africa, 2012



Source: International Energy Agency 2014.

efficiency and capacity, and increase silt deposition in reservoirs, thereby reducing the amount of water available for power generation (International Energy Agency 2012).

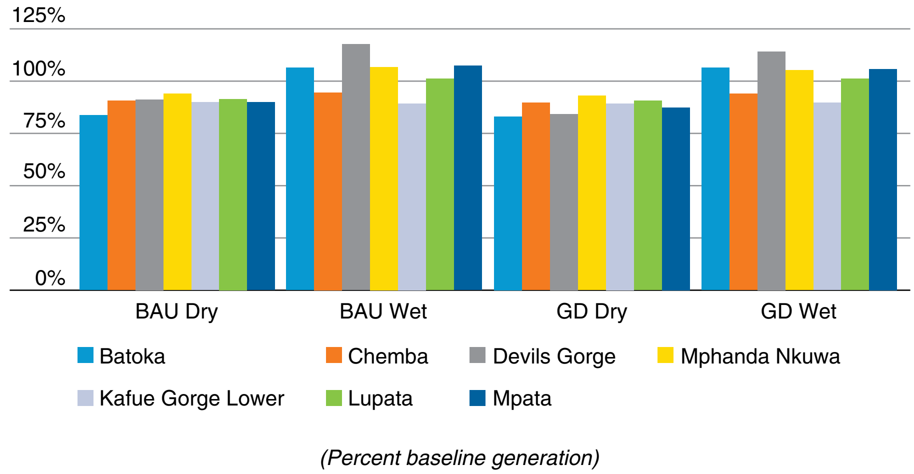
Increasing precipitation variability, on the other hand, reduces predictability of the timing and amount of water available, resulting in decreased reliability in hydropower generation. This would disrupt domestic and industrial electricity supply and decrease the attractiveness of beyond water productive investments that would contribute to jobs and economic growth.

Impacts of climate change on hydropower are expected to be significant in the Zambezi River Basin. The climate of the Zambezi is expected to get drier, diminishing water availability for hydropower generation. In the driest climate scenarios, in the absence of any adaptation of hydropower schemes in the Program for Infrastructure Development (PIDA) list as well as those prioritized in national master plans, the Zambezi Basin could lose up to US$42.1 billion in hydropower revenue between 2015 and 2050 (Cervigni, Liden, and Neumann 2015). Another study estimates that, in a drying climate, output from major hydropower plants in the Zambezi will decline by 10–20 percent (Spalding-Fecher, Joyceb, and Win 2017). Meeting established hydropower needs via increased production of coal-fired power will have implications for system costs in the regional electricity system and also increase greenhouse gas emissions (Spalding-Fecher, Joyceb, and Win 2017).

Figure A2 shows the potential loss in hydropower generation in a dry climate future compared to current generation (100 percent line), both under the current development trajectory ('Business as Usual', BAU), and under an optimistic scenario, with global commitment to sustainable development, regional economic integration, major investments in low carbon development, and technological advances ('Grand Deal', GD). While a wetter future (BAU Wet and GD Wet) would offer opportunities for increased hydropower generation, the estimated losses from decreased hydropower generation in a drier future (BAU Dry and GD Dry) are greater, furthering the need to plan for projected drier futures.

Beyond the direct link to hydropower, climate change has additional implications for the energy sector in Africa, felt through its impacts on traditional and conventional energy. Four out of five Africans are still dependent on solid biomass as a source of fuel (especially for cooking), as captured in Figure A1, and increasing hydrological variability, aridity, and droughts will reduce hydropower reliability and availability, subsequently increasing reliance on biomass. This could result in diminished feed stocks and increased land degradation due to vegetation loss. Thermal power supply or coal-based generation, on which most of southern Africa depends, is also exposed—coal mining relies heavily on water for extraction, processing, and slurry transport, among other processes, and as is the case for nuclear power plants, depends on water for cooling purposes. Warmer water temperatures reduce cooling efficiencies and can lead to reduced operations and even shutdowns (IPCC n.d.), jeopardizing energy security of households and economic activities.

FIGURE A2 Hydropower generation from dry and wet climates for major existing plants, 2011–2070



Source: Spalding-Fecher, Joyceb, and Win 2017.

Agriculture

Rain-fed cultivation accounts for over 95 percent of agricultural land in Sub-Saharan Africa (Wani et al. 2009). This makes farming particularly vulnerable to climate change, given the projected increase in interannual and inter-seasonal variability. The levels of annual rainfall, the nature of rainfall events, and the timing and length of the rainy season all impact rain-fed agriculture. For example, lesser than average rainfall levels during the cropping season can impair the development of regularly planted crops; intense rains can harm crops, so can prolonged dry spells between rainfall events, especially during the crop emergence phase; and finally, unseasonal rains can increase crop diseases (Water Research Commission 2009). Even for the less than 6 percent of land currently equipped for irrigation, rainfall affects the levels of water, the runoff and recharge of rivers or lakes, as well as future irrigation possibilities (You et al. 2010).

As a consequence of climate change, yields from rain-fed agriculture in some countries could be reduced by up to 50 percent by 2020, and by 2100, crop net revenue could fall by up to 90 percent (IPCC 2007a). While such impact will likely cripple small-scale famers, it poses serious risks to the economy at large and threatens food security in Africa (IPCC 2007a). Large numbers of marginal farmers, farmers cultivating agricultural land up to one hectare, could be forced out of production due to lack of adequate water for irrigation (FAO 2008).

Dryness implies a higher evapotranspiration, further increasing crop water requirements; increased evaporation and therefore an exacerbation of salinization and soil pollution; as well as an increase in pests and other diseases. Under the driest projected climate scenarios, in the absence of any adaptation of current irrigation plans, irrigation revenues in the Zambezi Basin could fall by up to US$7 billion compared to the no-climate change baseline for the period between 2015 and 2050 (Cervigni, Liden, and Neumann 2015). For the same period in the Nile Basin, such loss in irrigation revenues could reach US$13.2 billion in the Nile Equatorial Lakes region and US$0.8 billion in the Eastern Nile (Cervigni, Liden, and Neumann 2015). Chronic droughts could expand existing drylands in the Sahel by up to 20 percent (World Bank 2016a) in the worst-case dry scenarios, resulting in estimated irrigation revenue losses in the Niger Basin as high as US$0.8 billion (Cervigni, Liden, and Neumann 2015).

Industry

The industrial sector accounts for less than 5 percent of water withdrawals in Africa (FAO 2016). However, as countries across the continent pursue industrial development strategies and their economies make structural transitions from the primary to secondary and tertiary sectors, industrial consumption of total available water increases. This has been the trend in North America and Europe, where the industrial sectors account for 47 percent and

54 percent of water withdrawals, respectively (FAO 2016). Therefore, increasing uncertainty and depletion of water resources due to climatic factors pose a future challenge for the sector.

In the African context, beyond agriculture and hydropower, other industries that depend on water as an input will be impacted by reduced or more unreliable water availability, or diminishing water quality. This dependency results from water's role in the production process, as a component or cooling liquid, or from a reliance on hydropower energy. In the Limpopo Basin for example, mines depend on uninterrupted water supply to function.

In addition to its impact on productive water uses for industry, climate change will also affect industry through increased extreme events and associated costs. For example, floods in the Zambezi Basin destroyed infrastructure and affect a myriad of industrial activities, generating losses of over US$1 billion. In another example, in 2015, the south of Malawi and central Mozambique (along the Shire) were affected by devastating floods caused by heavy rainfalls following Cyclone Bansi, which disrupted industrial activities and resulting economic growth in the Shire Basin, but also throughout southern Africa.

Municipal supply

Close to 87 million people in Sub-Saharan Africa rely on unimproved sources of water for domestic use, and nearly 100 million for sanitation. Service provision for municipal water supply in much of the continent has been unable to keep up with the growth in demand for water, especially in primary and secondary cities. Municipal water supply in much of Africa is already characterized by high distributional losses, low billing collection, overstaffing, and under recovery of costs. Institutional frameworks are still insufficient, and most countries have yet to develop public private partnerships in this sector. Even today, this key driver of economic growth and development on the continent is struggling.

The effects of climate change coupled with projected water demand growth put municipal water supply in Africa deeply at risk. Infrastructure and governance systems must reckon with greater intermittency, seasonality, and variability of river flows. Preparing for such a future is costly: for example, climate change impacts on the Berg River in South Africa are estimated to account for 20 percent revenue loss for the water supply provider and 15.2 percent loss in social welfare (IPCC 2007a).

Navigation

Globally, climate change is expected to negatively impact inland navigation. River runoff levels during dry seasons may decline in many basins due to reduced or variable rainfall, and lake levels may fall due to reduced recharge and increased evaporation (IPCC 2007a). This has implications for transport along Africa's navigation corridors.

Ports too are at risk from climate change, including sea level rise as well as impacts from storm surges and changes in sediment flow. Given the critical role of Africa's ports in linking the continent to the global market, and the growth rate of cargo passing through ports, the impact of climate change on water resources is a key economic challenge for navigation (CDKN 2015).

2. Vulnerabilities in Rural Livelihoods

Water is key to livelihoods. It is crucial to people's survival, and necessary to ensure basic corporal and food hygiene. Moreover, in rural contexts, several rural subsistence activities are highly dependent on water. This includes activities of smallholder farming, fishing, and pastoralism. Climate change can thus affect living conditions and the viability of traditional subsistence activities. In extreme cases, the long-term consequences of climate and hydrology changes in specific regions can make these regions uninhabitable, forcing populations to move.

Rural livelihoods are likely to be vulnerable to climate-related shocks and stresses, as these affect water resources. In several African states, this vulnerability is heightened by the low levels of adaptive capacity of rural communities. This can be explained by the fragility of their environment. As discussed in Box 3, water security is more difficult to achieve in contexts that can be qualified as fragile, a sociopolitical characteristic which qualifies a significant part of Africa. Using data from the World Health Organization (WHO)/United Nations Children's Fund (UNICEF) Joint Monitoring Programme and the Fund for Peace, the World Bank has shown that fragility and access to improved sanitation and drinking water sources are closely correlated. In fact, access to improved sanitation and drinking water sources fall as fragility increases (Sadoff, Borgomeo, and de Waal 2017). Historical data (1990–2008) has shown that in Africa, fragile states have progressed more slowly in providing water supply coverage and water service delivery than non-fragile ones (World Bank 2011b).

Many African states have experienced difficulties in providing water services, protecting water resources and people from water-related disasters, and addressing water insecurity. This makes communities, especially rural ones, highly vulnerable to climate shocks impacting water resources. In Africa, climate-related shocks on water resources can have a tremendous impact on rural livelihoods, in particular when it comes to water supply and to sustaining key water-dependent subsistence activities.

In fragile and conflict-affected states, high levels of poverty, constrained resources, limited infrastructure, inadequate information, and weak institutions constrain the ability to adapt and build resilience to climate-related vulnerabilities. Appropriate macroeconomic policy, governance structures, social development features, and infrastructure that can help an economy withstand or recover from shocks and stresses are largely absent in fragile states.

In a recent report entitled *Turbulent Waters: Pursuing Water Security in Fragile Contexts*, the World Bank finds that in fragile states, where institutions and governmental structures lack capacity and legitimacy,[4] it is especially difficult for communities to build resilience to climate-induced shocks and stresses, which affect their water supply as well as their livelihoods (Sadoff, Borgomeo, and de Waal 2017). Lack of appropriate government action to tackle climate risks acts as a risk multiplier; "when institutions insufficiently and ineffectively respond to escalating risks of any kind, the ability of affected populations to cope with and build resilience to risks can be challenged" (Sadoff, Borgomeo, and de Waal 2017).

Water security, which is one key aspect of resilience, is also more difficult to achieve in fragile states. That is explained by a variety of factors, such as weak institutions and information systems, strained human and financial resources, and degraded infrastructure (Sadoff, Borgomeo, and de Waal 2017). Fragility tends to negatively impact levels of water security, and high levels of water insecurity in turn triggers social, political, and economic costs to a society. Water insecurity acts as a destabilizing force in fragile contexts, thereby fueling a vicious cycle.

Many countries or situations in Africa are considered to be fragile and are particularly vulnerable to climate change. Figure A3 shows the high number of countries affected by fragility, conflict, and violence, and highlights the areas where vulnerability to climate impacts is particularly stark.

Smallholder farming

Rural households and communities are vulnerable to changes in surface water's patterns and underground water's features, including those resulting from climate change. Rural livelihoods tied to agriculture are vulnerable to decreases in water availability, weaker predictability due to increased hydrological variability, and an increase in the consequences of poor and unsustainable management of the natural environment.

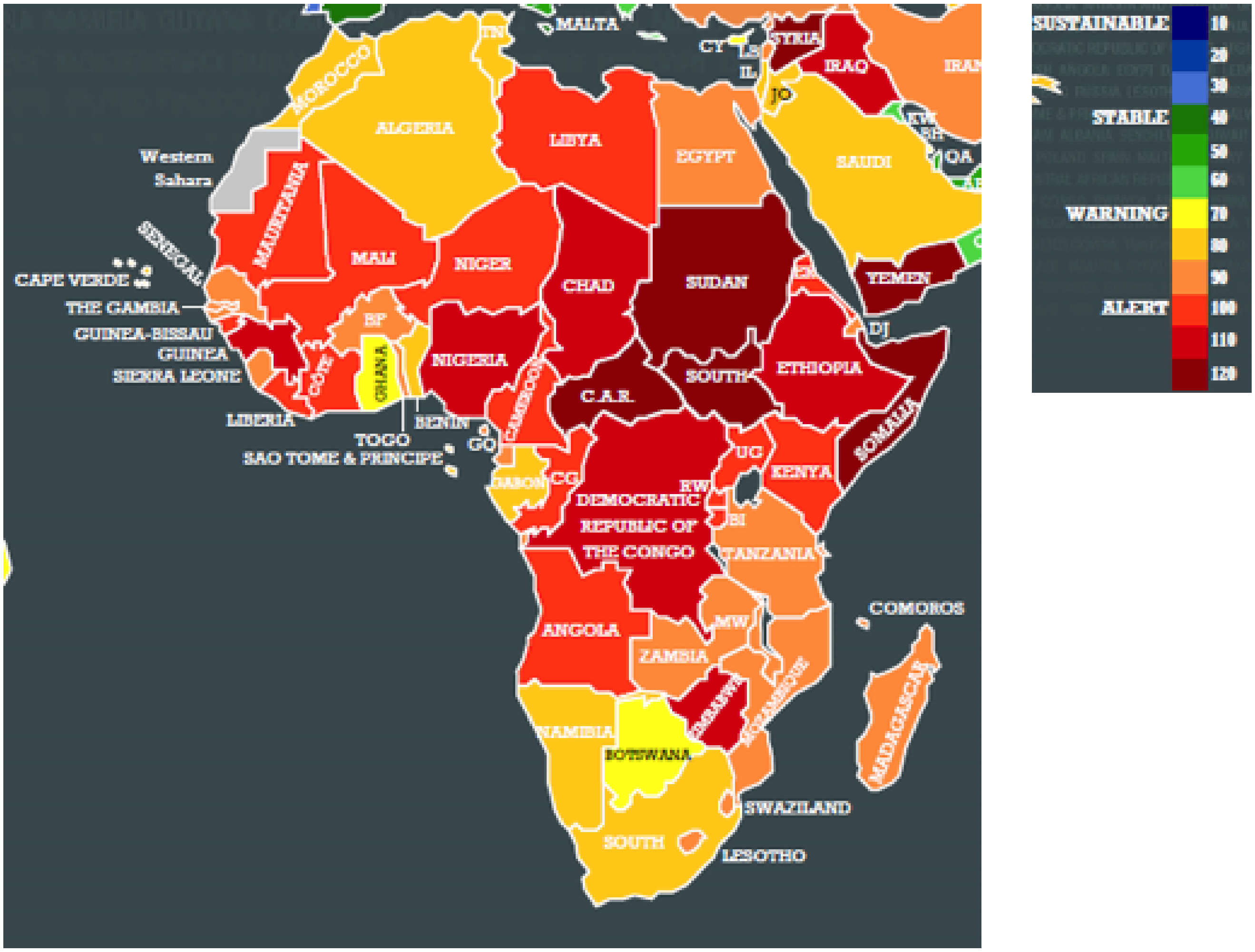
Reduction in water availability can disrupt subsistence and commercial activities of rural households, such as agriculture. Water stress has different impacts on different crop types, but overall the repercussions of inadequate or interrupted water for farming are largely negative. One consequence is reduction in crop yield (tied to both changes in water and temperature). A range of studies indicates that Africa will experience small crop yield reductions in the near term, and substantial reductions in the long term (for maize, wheat, millet, sorghum, groundnut, and cassava). Even though the near-term reductions are not staggering, they could take a greater toll on farm-based livelihoods due to a lack of time to adapt (World Bank 2013).

According to a recent analysis of 16 studies, west Africa displays a substantial risk of reduced crop yields, with an estimated 11 percent reduction by the 2080s. The west African region is home to 40 percent of Sub-Saharan Africa's population and contains over 50 percent of the cultivated area for cereal, root, and tuber crops. Rainfall in west Africa depends on the west African monsoon, on which climate projections show a great deal of uncertainty (World Bank 2013).

Rural communities are also vulnerable to disasters. Water-related natural disasters, floods, droughts, and storms, can harm individuals, destroy property, and affect the subsistence means of communities. Droughts are particularly harmful to rain-fed agriculture, and large floods can single handedly wipe away a whole year's crop.

4 The World Bank defines fragility as "periods when states or institutions lack the capacity, accountability, or legitimacy to mediate relations between citizen groups and between citizens and the state, making them vulnerable to violence" (World Bank 2011a).

FIGURE A3 Fragile states index



Source: Fund for Peace 2017.

Extreme climate events can also harshly impact the livelihoods of basin residents. Flood and droughts are deadly; in Niger, for example, droughts have caused famines, killing up to 250,000 people. In Ethiopia, the 2006 floods resulted in 700 deaths and displaced 242,000 people. In the Niger Basin, floods in 2012 destroyed hundreds of thousands of farm acres of land in Nigeria, displacing 1.3 million people and causing 431 deaths (Kandji, Verchot, and Mackensen 2006).

Floods and droughts can also affect subsistence activities. Floods, for example, damage or destroy crops, impacting harvest and possibilities of trading cash crops, which can lead to food insecurity and displacements.

Extreme climate events not only impact livelihoods through the actual disaster shock, they also—for the risks they present—push poor households to adopt low-risk strategies that have low returns, and leave no prospect of rising above the poverty line (Hallegatte et al. 2016). Such low-risk livelihood strategies tend to be based on excessive and costly diversification of activities and less-productive investments.[5] The Zambezi Basin provides a quantitative illustration of these strategies. In Zimbabwe for example, half of the costs relating to droughts were linked to "ante impacts from increased weather risk" (Elbers, Gunning, and Kinsey 2007). Another study has shown that extreme climate events—those that happen once every 30 years—could double the number of poor urban laborers in vulnerable countries like Zambia and Malawi (Ahmed, Diffenbaugh, and Hertel 2009). Such events of rare extreme

5 This constrains wealth accumulation and lowers incentives to invest in productive capital.

intensity could harshly affect urban laborers, increasing poverty rates of this group to 111 percent in Malawi and 102 percent in Zambia (Ahmed, Diffenbaugh, and Hertel 2009). According to Ahmed, Diffenbaugh, and Hertel, an increase in the intensity of extreme dry events leads to a rise of extreme poverty in developing countries; in this study, Zambia was expected to be the most severely affected country, with a rise of poverty by 4.64 percentage points by 2080 (Ahmed, Diffenbaugh, and Hertel 2009).

The regular occurrence of disasters can also compel rural communities to migrate. A long-term decrease in water availability can lead to migrations to other rural areas or to urban centers. Such migration is not without socioeconomic consequences in the host area.

The basins studied show a consistent increase in dryness and aridity. In the Niger Basin, for example, this increase is likely to result in a decrease in soil fertility and yields, impacting livelihood farming and pastoralism. Aridity can also increase pest infestations and crops stress, as is feared in the Nile Basin. In Chad, this aridity is likely to result in the movement of populations (especially subsistence farmers and cattle herders) toward greener areas, which can increase competition for land resources and tensions with host communities. The movement of population is mainly from the north to the south of the Lake Chad Basin. In the Limpopo Basin, increased dryness is expected to affect natural ecosystems such as wooded vegetation; this could impact the energy security of rural villagers, dependent on charcoal and fuelwood. Moreover, in poverty-stricken areas in the Mozambican part of the Limpopo Basin, as well as drier parts of Botswana and Zimbabwe, increasing climate dryness could make access to potable water and sanitation more difficult.

The effects of increased temperature are particularly important in the Zambezi region, as countries such as Angola, Namibia, and Zambia have a higher poverty exposure bias (poor people in those countries are more exposed to higher temperature than the rest of the population) (Hallegatte et al. 2016). In Chad, rise in temperature could also have tremendously negative effects; indeed, under certain climate scenarios, it is expected that 70,960 km^2 will no longer be usable for growing water-demanding crops[6] due to high temperatures (GIZ and LCBC 2015).

Fisheries

The impact of climate change on fisheries in Sub-Saharan Africa has not been studied as extensively as fisheries in some other parts of the world. However, the continent is likely to suffer the consequences of climate change on its marine and inland fisheries. As seen under Section 2.1, Africa is expected to suffer from higher temperatures, but also from alterations in rainfall patterns and increased aridity levels. Higher temperatures will heat water bodies in the continent and modify oceanographic conditions (Nellemann, Hain, and Alder 2008); reduced precipitation and greater evaporation will reduce the levels of water bodies in certain African regions, both directly and indirectly, as a higher quantity of water is likely to be used for irrigation to offset reduced precipitation (Brander 2007). By increasing the temperature of marine water and freshwater, and decreasing water levels and/or altering water regimes, climate change is likely to affect the physiology, behavior, growth patterns, development, reproductive capacity, mortality, and/or distribution of fish (Brander 2007). Climate change is also likely to affect fish indirectly, by altering the productivity, structure, and/or composition of the ecosystems on which fish depend for their survival (food and shelter) (Brander 2007). Lake Chad is an extreme example of climate change affecting water regimes, as increased aridity led to a drastic reduction of the Lake's surface and to a dramatic decrease in fish stocks (Coe and Foley 2001). A reduction in fish stock or an increase in the vulnerability of fish stocks to fishing activities would lead African communities to experience significant reduction of available protein due to disrupted fisheries; this will lead to economic and job losses.

Climate change may also result in certain species no longer being locally available where today's fisheries are based, or not being able to maintain critical populations. West Africa is once more a hotspot in this context, with studies finding that potential fish catches off the west African coast (where fish accounts for as much as 50 percent of animal protein consumed), are likely to be reduced by as much as 50 percent by the 2050s (relative to 2000 levels) (World Bank 2013).

6 Under the B1 scenario.

Rural water supply and pastoralism

Access to water supply in rural areas is also critical for pastoral livelihoods, in terms of adequate water for livestock health, as well as for a functioning ecosystem health to support pastoralism. Across much of Sub-Saharan Africa, climate change is likely to spur a shift from savanna grasslands to woody forests (this is driven more by temperature than water resource changes). Loss of forage is thus a key threat for pastoralists. Changes in hydrological patterns create a further risk for pastoralism: it reduces the options for diversification by constraining options that require water (such as irrigated forage production, and mixed-cropping with livestock). For instance, pastoralists in southern Ethiopia lost nearly half their cattle and roughly 40 percent of their sheep and goats to droughts in the period 1995–1997, and were limited in pursuing other farming options due to the diminished carrying capacity of the land (World Bank 2013).

Droughts create famines that decimate livestock; in Niger, it is estimated that droughts have decimated over two million livestock. In Limpopo, it is floods that led to the death of livestock (20,000 cattle lost in the flood event of 2000 in Mozambique alone). Floods can also increase waterborne diseases. Natural disasters can destroy homes and other infrastructure highly important for daily life. In the Nile Basin—where there is increased flood risk and storm damage—average annual flooding damages are estimated to be over US$25 million in riparian rural settlements of the Blue Nile and the Main Nile (especially Fogera and Dembiya, areas around Lake Tana).

3. Vulnerabilities in Ecosystems

An understanding of how climate change impacts natural ecosystems, including through changes in water resources, is crucial to the formulation of an economic argument for transboundary cooperation on the common water resource. It is ecosystems that produce goods and services that are beneficial to the economy and to the growth of basins' riparian states throughout Africa, and represent the foundation of productive activity in the continent.

The consequences of climate change on ecosystems are manifold, some more closely tied to water resources and others to temperature. Overall, studies suggest that Sub-Saharan African ecosystems will undergo marked change. In terms of species richness, for instance, research indicates that in a world that is 4°C warmer (by the 2040s), 10–15 percent of species endemic to the region will face the risk of extinction.

The negative effects of climate change on ecosystems are likely to be intensified by the lack of adaptive capacities developed in fragile African contexts. Fragile states are likely to show a limited ability or willingness to protect water resources and the ecosystems depending on these, from climate-induced shocks and stresses. The vulnerability of key natural features in Africa—aquatic biodiversity, aquatic ecosystems goods and services, and catchment lands—to climate-induced shocks and stresses is important to review to get a full picture of areas where resilience can be boosted through cooperative and forward-looking interventions.

Aquatic biodiversity

Aquatic biodiversity can be defined as the variety of life and the ecosystems that make up the freshwater,[7] tidal, and marine regions of the world and their interactions (Aqufind n.d.). Freshwater ecosystems are vulnerable to shocks or stresses created by a decrease in water availability or inconsistency in the supply of water; disasters; and poor and unsustainable management of the natural environment. Riverine ecosystems will be altered by climate change through changes in flow and runoff, which in turn affect the biotic environment. Wetlands are also susceptible to changes in the river flows and/or the inundation regime (World Bank 2010). Low flows coupled with high temperatures can place significant stress on freshwater ecosystems, while storm events can result in physical damage and change the morphological characteristics of river beds (and wetlands), in some cases resulting in dramatic changes in the system (Water Research Commission 2009).

Moreover, Africa's aquatic ecosystems are threatened by deforestation, the introduction of exotic plants and animals into rivers, the construction of dams and artificial lakes, the over-exploitation of fish catches, and finally, by increasing pollution (Chapman et al. 2003).

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7 Freshwater includes lakes, ponds, reservoirs, rivers, streams, groundwater, and wetlands.

Aquatic ecosystems goods and services

Rivers and lakes support critical ecosystem goods and services, ranging from water supply (for human consumption and for withdrawals for economic activity), to food supply (in the form of fish protein). Aquatic ecosystems are affected by droughts, floods, changes in river flows and runoff, and associated changes in nutrient load. As noted in earlier discussions, climate change is likely to have a detrimental impact on water supply and on the availability of fish protein. Aquatic environments provide additional ecosystem services such as the natural cleanup of water so it retains the properties that allow for human use. Disruptions by climate change in the form of variable rainfall and potentially lower flows (combined with impacts driven by temperature rise) could hamper water quality maintenance.

Finally, the increasing dryness and aridity expected throughout Sub-Saharan Africa are also likely to negatively impact natural systems. In the Nile Basin, increased dryness is expected to intensify thermal stratification in equatorial lakes, which in turn would increase algal productivity, microbial mineralization and reduce oxygen dissolution, impacting water quality, lake biodiversity, and ecosystem services. In Niger, a drier climate could result in 3,000 km^2 in the flooded area reduction (impacting aquatic biodiversity). In the Limpopo, reduced water availability is expected to affect inland coastal salinity, and coastal integrity. Salt water intrusion in the Lower Limpopo Basin region is expected to reach 30 km inland by 2030, over an area as large as 83 km^2 (INGC 2009). In Chad finally, aridity, coupled with industrial pollution, is expected to lead to an increased eutrophication of water resources.

Catchment land quality

Water resources in Africa will experience the impacts of climate change not only in direct ways, through an altered hydrological cycle, but also indirectly in the form of challenges to catchment land management, areas where rain and runoff water is collected by the natural landscape. Land use in catchment areas ranges from undisturbed natural land and woodlands, through agricultural and mining activities, to urban and industrial areas. Each of these plays a role in retaining rainfall and runoff water, as well as generating erosion and water quality impacts on receiving waters. Changes in land use result in significant changes in river hydrology and quality, and aquifer recharge.

Terrestrial ecosystems depend on catchment areas for their survival, and are thus indirectly impacted by climate change, through the impact on the water systems they depend upon. Changes in temperature and rainfall due to climate change impact the quality and size of water in catchments. The flow of water in a catchment, influenced by rainfall, can impact the sedimentation of the water body, for example. Catchments are also impacted by trends toward aridity. As aridity increases in large parts of the continent, evaporative losses are likely to leave several regions drier. This accelerates erosion and soil quality deterioration. Ultimately, disturbed or degraded catchments elevate the risk of floods.

Terrestrial ecosystems also depend on a healthy environment, which provides them not only with drinking water, but also with natural habitats to feed and reproduce. Humans also depend on well-functioning terrestrial ecosystems, both for the goods and services they provide. Goods are countless and include medicinal plants, services include flood attenuation, carbon sequestration, possibilities for tourism, among many others. Trends toward aridity will impact the survival of terrestrial ecosystems, and on all species depending on them.

B Overview of Five Major Transboundary Basins in Africa

Nile River Basin, NBI, 2012.

NILE BASIN

River length: 6,695 km

Basin area: 3.2 million km^2 across 11 countries (10 percent of the African continent)

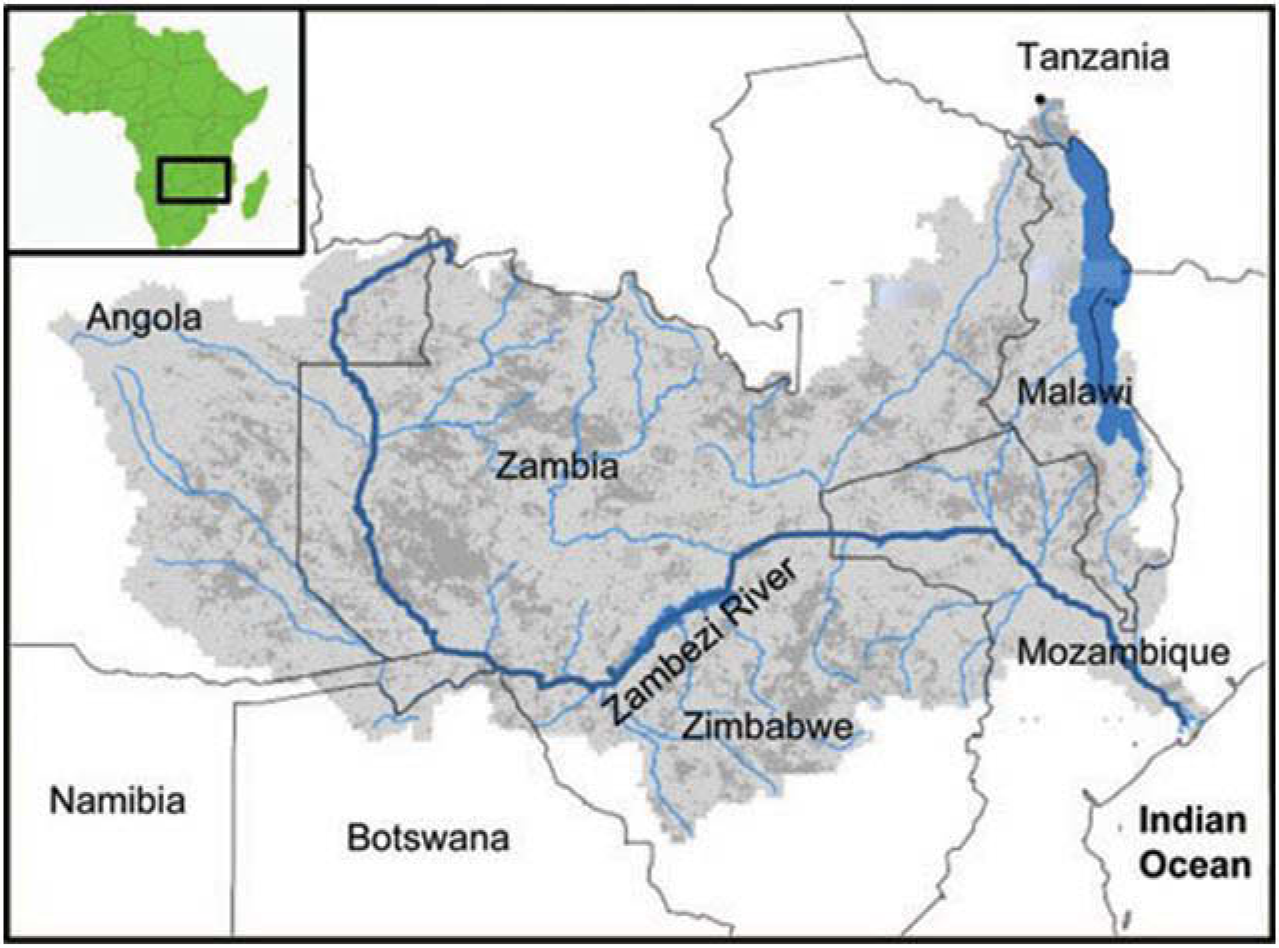
Basin countries: Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, South Sudan, Tanzania, Uganda

Basin population: 238 million

Major environmental assets: Sudd Wetland, Lake Victoria

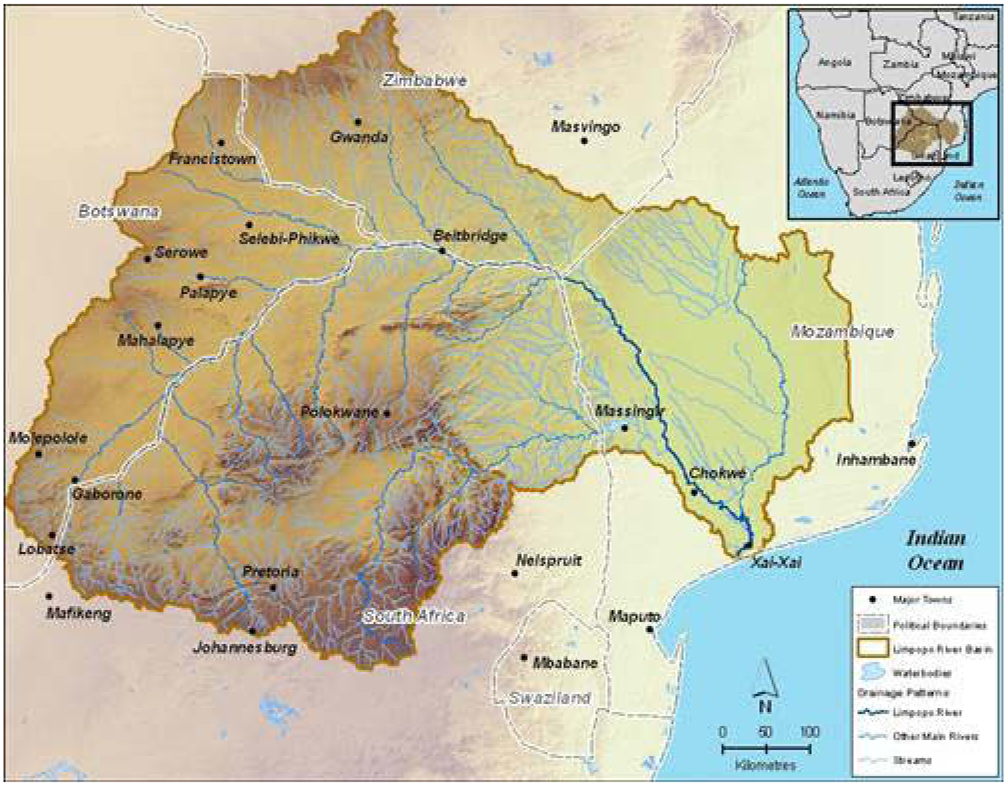
Challenges: High population growth, water scarcity, soil loss, salinization

Transboundary water institutions: NBI, comprised of three centers—Nile-Secretariat (SEC), Eastern Nile Technical Regional Office (ENTRO), Nile Equatorial Lakes Subsidiary Action Program (NELSAP-CU)



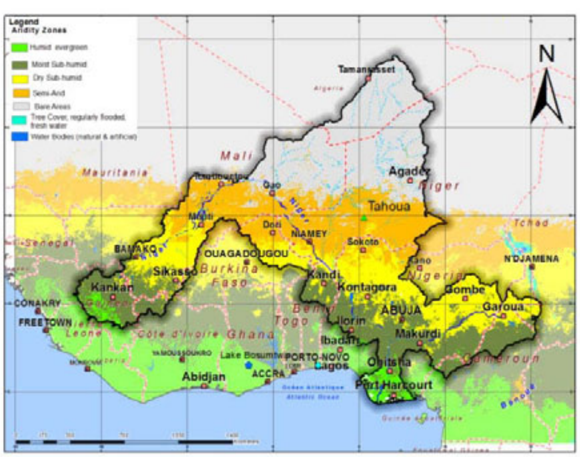
Zambezi River Basin, PHIRI, 2007.

ZAMBEZI BASIN
River length: 2,700 km
Basin area: 1.3 million km^2 across 8 countries
Basin countries: Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, Zimbabwe
Population: 47 million
Major environmental assets: Zambezi Delta, Lake Malawi
Challenges: High population growth, urbanization, income inequality, extreme weather events, land degradation, deforestation
Transboundary water institutions: ZAMCOM, ZRA



Limpopo River Basin, Hatfield, 2010.

LIMPOPO BASIN
River length: 1,750 km
Basin area: 412,938 km^2 across 4 countries
Basin countries: Botswana, Mozambique, South Africa, Zimbabwe
Basin population: 14 million
Major environmental assets: Transboundary aquifer in Upper Limpopo, biodiversity hotspots
Challenges: Full allocation of water resources, extensive extractive industry, severe floods and droughts, income inequality, urbanization
Transboundary water institution: Limpopo Watercourse Commission (LIMCOM)



Niger River Basin, BRLi, 2007.

NIGER BASIN
River length: 4,200 km
Basin area: 1.5 million km^2 across 10 countries
Basin countries: Algeria, Benin, Burkina Faso, Cameroon, Chad, Guinea, Ivory Coast, Mali, Niger, Nigeria
Basin population: 100 million
Major environmental assets: NID wetland
Challenges: Income inequality, extreme poverty, sub-regional security threats, extreme weather events
Transboundary water institutions: NBA

Lake Chad Basin, WWF.

LAKE CHAD BASIN

Lake area: 2,500 km² today (approx. 10 percent of its size in the 1970s)
Basin area: 2.4 million km² across 8 countries (8 percent of the African continent)
Basin countries: Algeria, Cameroon, Central African Republic, Chad, Libya, Niger, Nigeria, Sudan
Population: 30 million
Major environmental assets: Transboundary aquifers
Challenges: Varying lake size, extreme poverty, sub-regional security threats, land degradation, biodiversity depletion
Transboundary water institution: LCBC

C Dependency and Impact of Demographics and Economics on Water Resources in Africa

In this annex, we review the dependency relation of African societies and economies with water resources. Moreover, we study the impact of African demographic and economic features on the water resources. Because of the transboundary nature of most water resources on the continent, such impact is often not only national but also transboundary. This section thus begins with highlighting the dependence of people and economic development on water; it then turns to a review of the structure of the economy Africa, followed by a review of demographic data. Finally, the development stress on water is formulated.

This section shows that development and growth are current realities in the Africa continent, and that this will inevitably lead to increased pressure of the water resources in the short to medium term. Indeed, development and growth in Africa are and will continue (medium term) to be generated by the economic sector depending on and impacting the water resource, such as the agriculture, extractive, and manufacturing sectors. The next section studies how climate change's current and future manifestation are likely to add pressure to the water resource (in a horizon spanning from today to the longer term).

1. The Dependence of People and Economic Development on Water

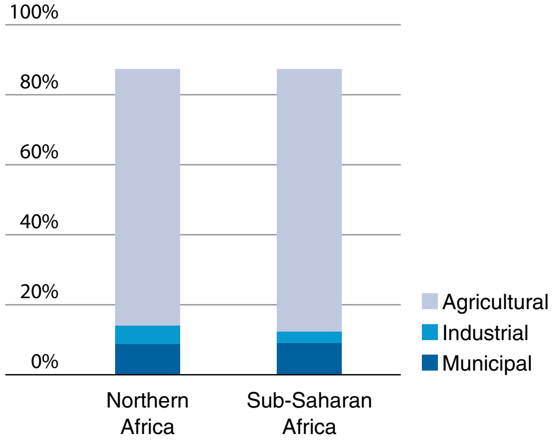
The livelihoods of many people in Sub-Saharan Africa, especially the rural poor, are closely intertwined with the water resource. Rain-fed agriculture, fishing, and cattle grazing are means of subsistence for the majority of the rural populations in Africa. Beyond this micro-level assessment, on the macro level, economic and social development on the African continent is dependent upon water.

African economies rely mainly on the primary sectors (extraction or harvest of products from the earth) and the secondary sectors (manufactured goods) of the economy. As part of the primary sector, the extractive industry is an important driver for development in the continent; 11 African countries rank among the top ten sources for at least one major mineral, and Africa produced about 13 percent of global oil in 2015, up from 9 percent in 1998. Moreover, agriculture is Africa's largest economic sector, representing 15 percent of the continent's total GDP (equivalent to over US$100 billion annually). Turning to the secondary sector, it is expected to boom together with the growth of the African consumer goods market (representing 200 million Africans in 2015) (McKinsey&Company 2010).

While the tertiary sector is growing (such as banking and telecommunication), African growth is expected to be driven by the growth of the primary and secondary sectors. Those are highly reliant on water, with agriculture requiring irrigation, and manufacturing industries requiring hydropower.

Understanding agriculture in Africa is central to understanding the dependence of people and economic development on the

FIGURE C1 Total water withdrawal by sector (around 2003)



Source: www.fao.org/nr/aquastat accessed Nov 2010

Note: Municipal use: 9 percent and 10 percent of total water use in northern and Sub-Saharan Africa respectively; industrial use: 6 percent in northern Africa and 3 percent in Sub-Saharan Africa.

continent. Agriculture is by far the biggest water user in Africa, using 85 percent of water withdrawals in northern Africa, and 87 percent in Sub-Saharan Africa (FAO 2016).

Agriculture is vital for the food security of the continent, and an important factor in the African trade balance. Despite the importance of agriculture for the continent, and despite the massive extent of arable land lying in the continent (more than one-quarter of the world's arable surface), the proportion of land under irrigation is only 7 percent across Africa, and 3.8 percent in Sub-Saharan Africa. Two-thirds of irrigated land in Africa is found in only three countries: South Africa, Madagascar, and Sudan. Africa's agro-ecological potential is massively larger than its current output, and increasing productivity will be key to ensure food security at a continental and even global scale. Moreover, growing productivity is key to increasing exports and to meet the huge potential of growth in the agricultural sector (Africa today generates only 10 percent of global agricultural output, and the growth rate is moderate, about 2–5 percent a year.) (McKinsey&Company 2010).

Beyond agriculture, the connectivity and interdependence between the economic and social spheres and the water sector is increasingly recognized by African states, and increasingly apparent in their national strategies. The emerging paradigm of 'Water for Growth and Development', found in numerous national development strategies places water at the center of national strategies to grow the economy, eradicate poverty, and provide social goods and services. Water availability, together with water quality and questions of scarcity, has a growing impact on development planning and on the development pathways of many African countries (Water Research Commission 2009).

2. Structure of the Economy across Africa

To make the economic argument that cooperation builds climate resilience in national and regional economies, it is important to understand the structure of the economy across Africa.

A. GDP and employment

Between 2000 and 2010, the African continent achieved an average real annual GDP growth of 5.4 percent (equivalent to US$78 billion annually to GDP, in 2015 prices). Over this period, Africa has been the fastest-growing continent most years, surpassing Asia. This growth was driven primarily by growth in sales in commodities, services, and manufacturing (The Economist 2011). The nations experiencing the highest growth included Mauritania, Angola, Sudan, Mozambique, and Malawi, with respective growths of 19.8 percent, 17,6 percent, 9.6 percent, 7.9 percent, and 7.8 percent in 2007 (BBC News 2007). The economies of Rwanda, Mozambique, Chad, Niger, Burkina Faso, and Ethiopia were also growing fast.

However, growth slowed down to 3.3 percent (US$69 billion) a year between 2010 and 2015 (Barton and Leke 2016). This growth deceleration has been mainly driven by poor numbers in oil exports (from Algeria, Angola, Nigeria, and Sudan)[8] and by the poor or inexistent growth of northern countries, bearing the stigma of the Arab spring political uprising.[9]

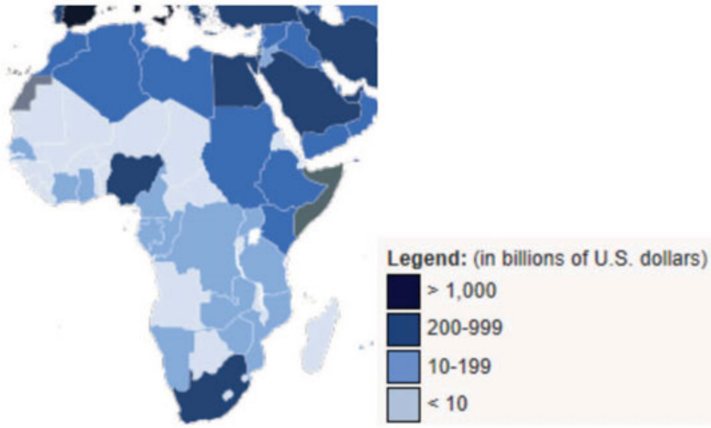
Despite these shocks hitting key economies, the rest of Africa continued its growth path, with stable rates of GDP and productivity growth from 2010 to 2015: real GDP grew at an annual rate of 4.4 percent (similar to the 2005–2010 numbers), and productivity at an annual rate of 1.7 percent (similar to the 2000–2010 numbers) (Barton and Leke 2016). Most African countries have managed to start diversifying their economy. Trade, especially with China and India, has been boosting growth in Africa, especially since the turn of the century. Fast growth is also explained by the natural resources of Africa, and by the growing political stability on the continent. The service, manufacturing, and construction sectors have been booming lately; between 2010 and 2014, the services sector generated 48 percent of Africa's GDP growth (up from 44 percent in the 2000–2010 period). During the same period, the manufacturing sector represented 4.3 percent yearly and the utilities and construction sectors expanded to generate 23 percent of Africa's growth (Barton and Leke 2016).

Despite this growth and endowment with natural resources, many people still live in poverty on the African continent (World Bank n.d.), due to the poor distribution of wealth among the population and to weak institutions.

8 The growth rate of those countries fell from 7.1 to 4 percent.

9 The economies of Egypt, Libya, and Tunisia did not grow between 2010 and 2015 (though in the previous decade they grew on average 4.8 percent yearly).

FIGURE C2 World map showing nominal GDP of countries for the year 2010 according to the International Monetary Fund (IMF)



Source: https://en.wikipedia.org/wiki/List_of_continents_by_GDP_(nominal)

Even though over the past five years, the African continent has seen a creation of 21 million new jobs in the formal economy (53 million since 2000, a job growth rate of 3.8 percent), this is far from matching the needs for growth (Barton and Leke 2016). Unemployment among youth and the adult population is high. As revealed by the African Development Bank, the informal sector contributes about 55 percent of Sub-Saharan Africa's GDP and 80 percent of the labor force, and 9 in 10 rural and urban workers have informal jobs (AfDB 2013). Most informal sector's employees are women and youth. The informal sector does provide opportunities for the poorest and most vulnerable people, but it also goes along with insecurity of income, weak employment conditions, and a lack of social protection (AfDB 2013).

B. Projected economic growth and sector diversification (dependency)

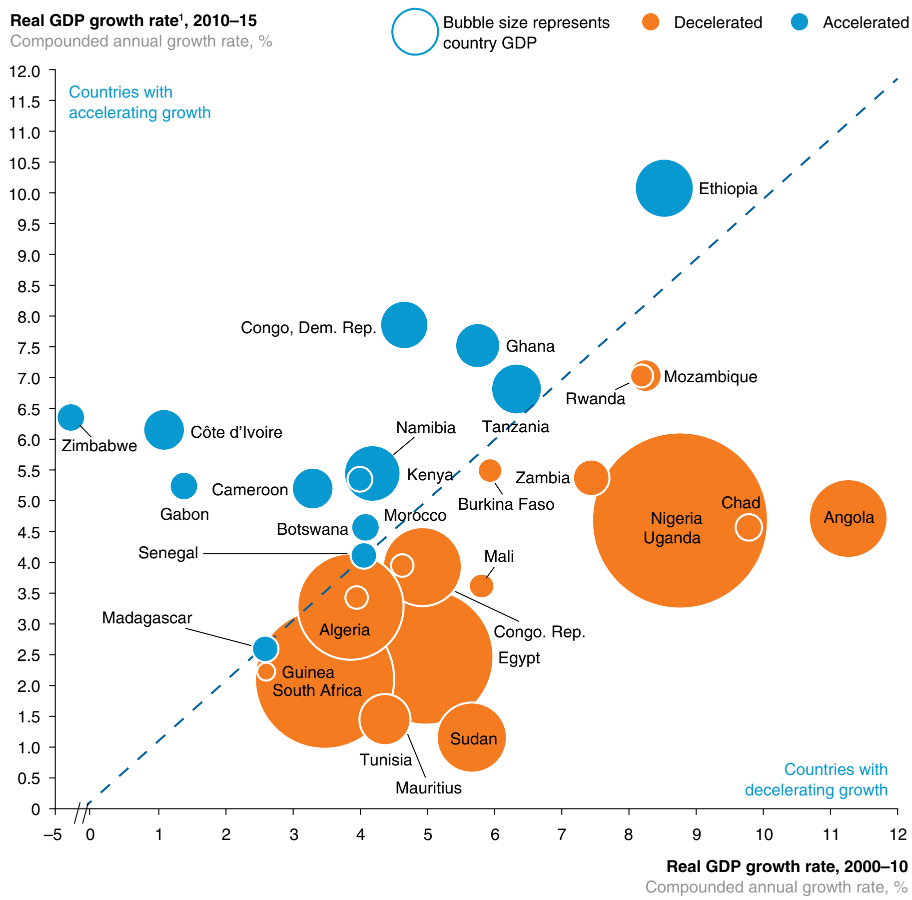
Growth in Africa is expected to last. A few years ago, it was expected that the African GDP would rise by an average of over 6 percent a year between 2013 and 2023 (August 2013). Sub-Saharan Africa was expected to reach a GDP of US$29 trillion by 2050 (Robertson 2013). Now, because world trade is growing at a relatively slow pace due to the drop of global commodity prices, projections have been scaled down (Sharara 2016). The IMF still forecasts that Africa will be the second-fastest growing region in the world between 2016 and 2020, with annual growth of 4.3 percent (Barton and Leke 2016).

However, as highlighted by the World Economic Forum (WEF), three powerful positive trends are likely to sustain Africa's growth in the long run: first, Africa's growing labor force;[10] second, its ongoing urbanization and the potential for increasingly productive activities;[11] third, the African economies are well positioned to benefit from technological change (with the opportunities of unlocking growth and leapfrogging the limitations and costs of physical experiences elsewhere) (Barton and Leke 2016). In addition to those trends, the rise in infrastructures investments, which doubled over the past decade, is another great sign for future growth (Barton and Leke 2016).

Investors have well understood the potential of Africa, and foreign direct investment (FDI) increased from US$14 billion in 2004 to US$73 billion in 2014 (Barton and Leke 2016). Investments are likely to continue flowing in the continent, owing to increasing political stability, and because the rate of return on investment in Africa is currently the highest in the developing world (McKinsey Global Institute n.d.). Africa's economy is expected to improve its performance in the future, also because education is improving on the continent.

10 See demographic section below. A young population and growing labor force is highly valuable in an aging world.
11 See urban and rural population section below. Productivity in cities is on average three times as high as in rural areas, representing some great growth opportunities for the continent.

FIGURE C3 Growth on the African continent



Source: World Economic Outlook, IMF, April 2016; McKinsey Global Institute analysis.

Challenges also lie ahead, such as the price decrease of oil and other commodities, African governments' budget deficit (above 6.9 percent of GDP in 2015), political instability, and violence (Barton and Leke 2016). Without addressing those challenges, growth can stagnate (as was the case in Botswana, Cameroon, Côte d'Ivoire, the Democratic Republic of Congo, Ethiopia, Gabon, Ghana, Kenya, Madagascar, Namibia, Senegal, Tanzania, and Zimbabwe in 2016) or slow down (Barton and Leke 2016).

Looking at macroeconomic stability, economic diversification, and political and social stability, the WEF classified major African economies as growth stars, unstable growers, and slow growers. Growth stars, with high rates of growth and a high score on stability (Côte d'Ivoire, Ethiopia, Kenya, Morocco, and Rwanda) accounted for one-fifth of Africa's GDP in 2015. Unstable growers, having had high growth rates over the past five years linked to their resources but lower scores on stability (Angola, the Democratic Republic of Congo, Nigeria, and Zambia), accounted for 43 percent of Africa's GDP the same year. Slow growers (South Africa, Madagascar, Egypt, Libya, and Tunisia) account for 38 percent of GDP in 2015 (Barton and Leke 2016).

The majority of African countries are heading toward a 'middle income' status (defined as a minimum of US$1,000 per person a year). This means a growing consumer class with a higher income to spend on discretionary spending (rather than necessities); this in turn means an increase in regional consumption, in addition to global growth in demand (including from trade partners from the developing world, such as China). Household consumption in Africa grew at a 4.2 percent compound annual rate in the last five years (US$1.3 trillion in 2015). The WEF estimated that Africa's consumers will spend US$2 trillion by 2025 (Barton and Leke 2016). Consumption is high in cities (75 African cities accounted for 44 percent of total African consumption in 2015), and in certain countries such as Nigeria (Nigerian consumers may account for up to 30 percent of Africa's consumption growth over the next decade.) (Barton and Leke 2016).

Africa's long-term growth will depend on the ability of public and private stakeholders to strengthen and reform their socioeconomic system by diversifying the sources of revenue to gain stability, reforming financing systems (tax and customs collections), setting up or improving social nets, expending financing services, planning urbanization ahead, expending power supply, improving access to and quality of education, and taking steps to further regional integration, among others (Barton and Leke 2016).

3. Demographics

As of 2012, approximately 1.07 billion people were living in 54 different countries in Africa (Population Reference Bureau 2013). The quick evolution in Sub-Saharan Africa's demographics—with high population growth and movement of population, mainly from rural to urban settings—is driving demand for water and accelerating the degradation of water resources. Reviewing the continent's demographic trends is thus crucial to understand the issues of dependency to water and vulnerability to shocks and stresses. In the following, we review the demographic structure of Africa.

A. Population, demographics, and human development

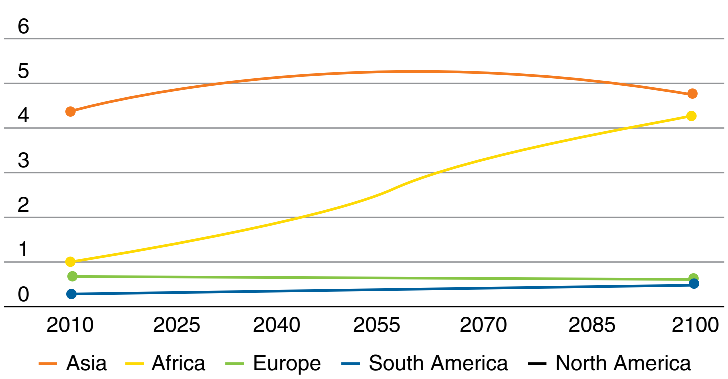
Africa is in the midst of an impressive democratic shift. According to the African Bank, Africa's population is likely to more than double by 2050, to reach 2.4 billion people (AfDB 2014b). In the first half of the 21st century, Africa is expected to record the highest population growth in the world. At the close of the century, some projections indicate that Africa would reach 4.2 billion (The Economist 2014). The fastest growing regions within the continent are east and west Africa.

This massive population growth in Africa leads to a demographic transition, which sees an increase in populations of productive age. This number is booming and unlocking opportunities for economic development.[12] In 2034, Africa is expected to have the world's largest working-age population of 1.1 billion (Barton and Leke 2016). This economic potential will translate into actual development if the necessary policies and initiatives are adopted—in domains such as education, investments, business development, and so on (African Development Fund and WWF n.d.).

A fast-growing population has implications for growing demands for water, food, energy, and other natural and manufactured resources, as well as growing demands in housing, transport, sanitation, and security, among other basic necessities. These growing demands are associated with a growing impact on Africa's ecology (ecological footprint) (African Development Fund and WWF n.d.).

Turning to current human development data, Africa is faced with great challenges, despite significant progress in recent years. Africa lies behind the rest of the world when it comes to access to safe water and sanitation, as well

FIGURE C4 **Population, world regions 2010–2100**



Source: African Development Bank.

12 In the 1980s, Sub-Saharan Africa counted one working-age person for each economically inactive person. "Can It Survive Such Speedy Growth?" *The Economist*. The Economist Newspaper, August 23, 2014.

as access to electricity. A significant part of the population of the continent must walk long distances to collect water; currently only 54 percent of households in Sub-Saharan Africa have water within 15 minutes from the household (42 percent in rural areas and 74 percent in urban areas).[13] The Organisation for Economic Co-operation and Development (OECD) estimated that about 620 million Africans do not have access to electricity, and 730 million do not have access to modern cooking facilities (OECD/International Energy Agency 2014), which has implications on health and education, among others (International Renewable Energy Agency 2013).

B. Migration and growth

Internal migration and displacement is a current trend on the African continent, resulting from lack of economic opportunities, political instability, conflicts, and natural disasters. The lack of opportunities and natural disasters are often linked to climatic conditions. In the first case, a variable or changing climate, especially when manifesting in drier climates, can make it highly difficult for individuals and communities to prosper or even survive in rural areas. This can be a push factor, sending communities toward places where they perceive they would have increased opportunities to acquire land or get a job. Migration often involves a rural-urban shift, as urban centers are perceived as offering better job opportunities. In the second case, migrants flee disasters which, in most cases, are climate related (Water Research Commission 2009).

Increased migration is a likely consequence of climate change. Climate change is indeed expected to manifest in a drier and hotter climate, which will make resources more scarce, leading to increased competition. A decrease in rainfall due to climate change will make rain-fed agriculture more difficult or even impossible in certain regions. Moreover, as will be discussed in Annex D, *Climate Variability and Change*, climate change is likely to increase the frequency and intensity of disasters.

Migration is not without consequences on the social and economic equilibrium of a country. Migration can result in increased pressure on specific rural areas, increased social tensions, increased exposure of vulnerable groups to inequalities, and increased stress on urban structures such as water supply systems (Water Research Commission 2009). Migration beyond the African continent can also have negative consequences, such as a skills loss (brain drain) (African Development Fund and WWF n.d.).

C. Urban and rural populations

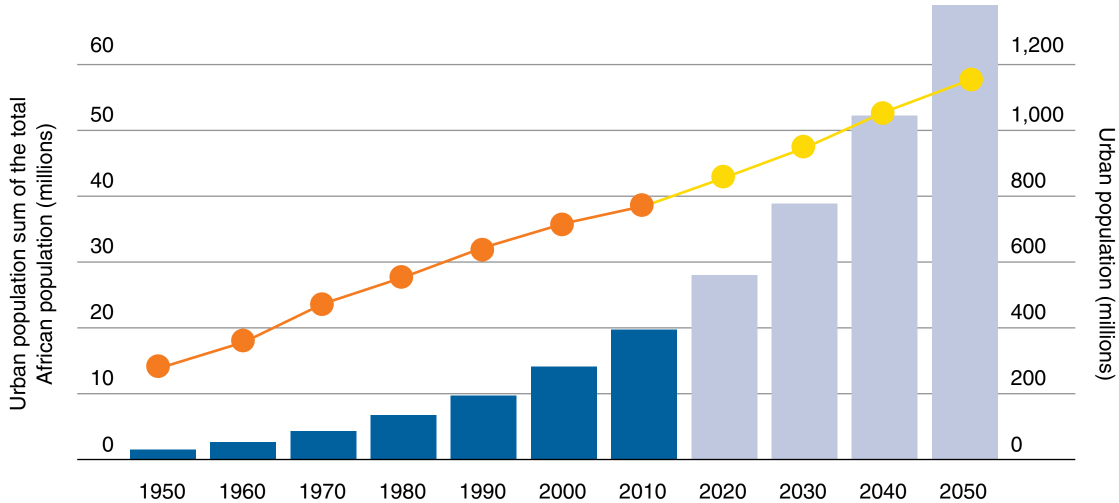
Africa has the highest rate of urban population growth worldwide (African Development Fund and WWF n.d.). In 2014, Africa had 52 cities with a population of over a million (AfDB 2014b), and by 2030, it is expected that almost half of the population of the continent will be urban residents (AfDB 2014a). According to the UN, over the next decade, an additional 187 million Africans will live in cities (Barton and Leke 2016). This urban growth is the result of high birth rates in urban centers but also of migration from rural to urban centers. Cities are expected to offer better job and education opportunities, as well as better access to health care.

Unfortunately, about 61.7 percent of Sub-Saharan Africa's urban population lives in slums (UN-Habitat n.d.), and most jobs are to be found in the informal sector. Indeed, a characteristic feature of Africa's urbanization is that it is not accompanied by industrialization, as is and was the case in most parts of the world. Informal jobs lead to poor and intermittent salaries, as well as low levels of contribution to the tax authorities, and thus reduces local economic development opportunities through municipal services provision (sanitation, water supply, and so on) (African Development Fund and WWF n.d.). Additional climate-change-related challenges are likely to hit informal settlements' weak infrastructure, such as an increase in storms and flash flooding.

To sum up, Africa's economy is developing rapidly, with a strong dependence on the water resource. Africa's demographic features are also undergoing some rapid changes, with a growing urban population.

13 In the majority of countries in Africa, less than 50 percent of the population has access to improved sanitation facilities (30 percent in Sub-Saharan Africa) and less than 75 percent of the population has access to improved drinking water sources. African Ecological Futures—Working document.

FIGURE C5 Urban population trend, Africa, 1950–2050



Source: African Development Bank.

4. The Development Stress on Water

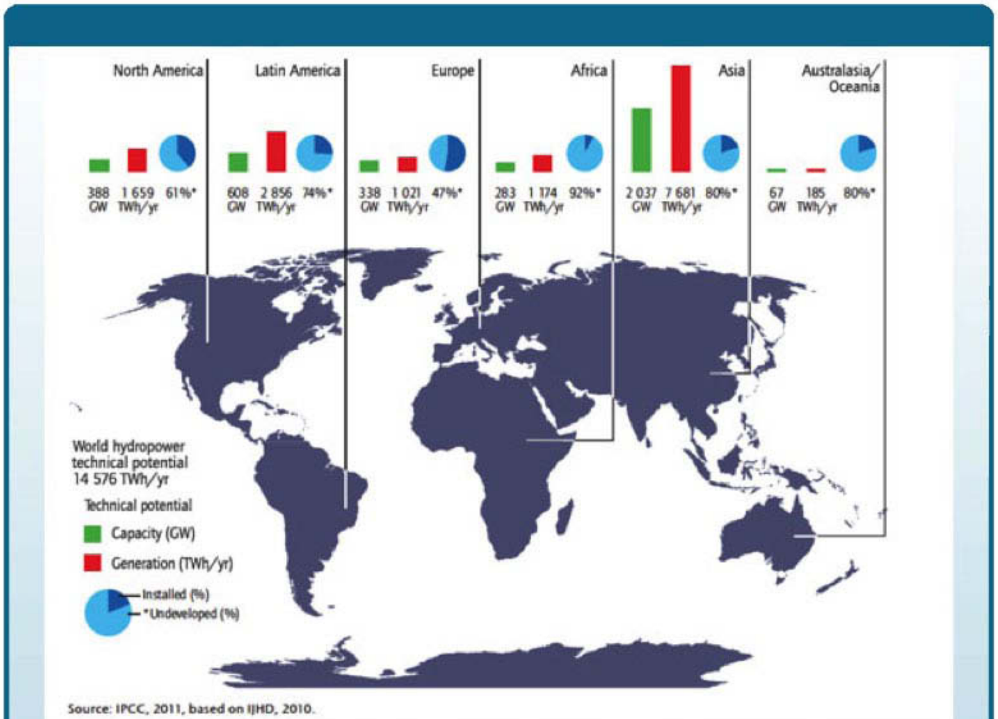
Economic and demographic growth add pressure on the water resource, by influencing water demand and availability. Population growth means an increasing number of people to feed, and thus an increasing demand for agriculture, which is already Africa's largest economic sector. Moreover, economic development in Africa is linked to the growth in the secondary sector, an energy-intensive sector; the energy need of the secondary sector is to be met with the development of renewable energies, such as hydropower, an important source of energy on the continent.

Moreover, Africa's socioeconomic development may impact the adaptive capacity of African states, influencing the quantity and quality of information available, the adequacy of infrastructure, and the strength of institutions.

For example, the undeveloped hydropower potential in Africa is estimated to reach 95 percent (see Figure C6) (IPCC 2011). In the coming decades, the development of hydropower on the continent will add pressure to the water resource.

In conclusion, the development trajectory that the African continent will adopt will impose challenges on water resources.

FIGURE C6 Potential for hydropower development



Compared to the rest of the world, Africa has been slow in taking advantage of its electricity generation potential.

Source: http://www.hydroworld.com/articles/print/volume-21/issue-6/articles/african-hydropower/hydro-in-africa-navigating-a-continent.html

D Climate Variability and Change in Africa and Impacts on Water

Annex A reviewed the strong dependency of the people and the economies of Africa on the water resource for growth and development. The impact of demographic and economic growth on water resources, creating so-called development stresses, was also studied. This annex shows how climate variability and change exacerbate this development stress. To that end, Africa's climate zones are reviewed, a climate change picture is drawn, and climate change implications for transboundary water resources are listed. The impact on Africa's transboundary basins to climate stressors and shocks is assessed, and finally the impacts of climate-change-induced water shocks and stresses on development trajectories are reviewed.

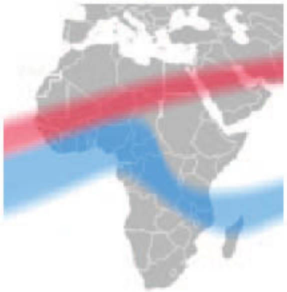
This study of the impacts of climate change is particularly relevant in Africa, both because the continent is in a sensitive phase as it is engaging in a historically rapid phase of development, but also because Africa is expected to be the continent that will be the most affected by climate-change-induced rise in temperature. This annex highlights how important building resilience throughout Africa will be, immediately and also in the long run.

1. African Climate Zones: General Hydrology and Climatic Zones

Straddling the equator from 37°N to 35°S, the African continent is dominated by tropical and subtropical climate zones. The zones are mostly derived from the presence of the Inter-Tropical Convergence Zone (ITCZ). The ITCZ develops as a band around the equator where the trade winds of the northern hemisphere and those of the southern hemisphere converge, and force moisture-laden air upwards. This upward convection typically produces heavy rain in the form of short but intense thunderstorms (Water Research Commission 2009).

The ITCZ varies in location throughout the year (see Figure D1), leading to variation in rainfall in equatorial countries and in countries further from the equator. Longer term changes in the ITCZ can result in severe droughts or floods. The ITCZ influences the climate of different parts of the continent throughout the year.

FIGURE D1 Map of the ITCZ in January (red) and July (blue)



Source: Wikipedia, 2009.

Southern Africa

Rainfall in southern Africa is strongly influenced by the ITCZ. During the dry season, the ITCZ can exert an influence between mid-Tanzania and southern Zimbabwe (UNEP 2002). The ITCZ moves to the south during the southern hemisphere summer months (November to March), bringing rainfall to the southern African subtropical countries; however, the effect is weakened in the western parts of southern Africa, as a result of the Atlantic and Botswana high-pressure cells.

Rainfall along the southeastern coast of Africa can be strongly influenced by tropical cyclones, with very heavy rainfall (also in excess of 2,000 mm) associated with landfall of the Indian Ocean tropical cyclones during the December to April period (Water Research Commission 2009). These storms follow parabolic paths, moving from the northeast toward Madagascar before curving to the southeast, often striking western Madagascar. Occasionally they travel down the Mozambique Channel making landfall along the Mozambique coastline, and then sometime up the Zambezi valley onto mainland Mozambique and Zimbabwe.

High-pressure systems dominate the winter months in subtropical Africa. The Atlantic and Indian Highs link with the Botswana High to form a more-or-less continuous high-pressure band across southern Africa from May to September. During winter, the westerly winds and frontal troughs of the mid-latitudes allow temperate cyclones to shift sufficiently toward the equator bringing frontal rain to the southern part of Africa. Frontal rainfall in the winter rainfall areas, notably the western cape of South Africa, results in up to 800 mm mean annual rainfall, although rainfall in some of the mountainous regions can be much greater (over 2,000 mm).

West Africa

The climate of west Africa varies greatly from the north to the south of the subregion; the zones along the border of the Sahel covering Mauritania, northern Senegal, Mali, and Niger are desert and semi-desert regimes. These are characterized by low annual precipitation (100–300 mm) and high evaporation rates (more than 4 m/year) (UNEP 2002). Drought is a recurrent problem in the Sahelian zone of western Africa.

On the other hand, the south and the coast are much wetter. In the south of the subregion, temperatures are lower, and floods occur because a combination of the marked hydrological degradation, relatively high runoff, and large areas of flatland. Most rainfall occurs between May and September, the ITCZ moves north of the equator, bringing rain to west Africa. The coastal zone of west Africa is among the wettest regions in Africa, with more than 3,000 mm of ITCZ-driven rainfall throughout the year.

The climate of the west African subregion also varies according to the season, mainly due to the movement of the ITCZ. There is substantial interannual variability in precipitation with no perennial runoff and flash floods occurring in small basins during rainy periods.

East Africa

East Africa frequently experiences a deficit in rainfall and droughts. At least one major drought has been recorded in the subregion in the past 40 years. By contrast, some areas have experienced above average rainfall, triggered by the ENSO and ITCZ phenomena. The movement of the ITCZ brings rainfall in the east of Africa, including to the Horn, between May and September; during this wet season, rainfall reaches about 800–1,600 mm, and can even exceed 1,600 mm in some places, notably the Ethiopian highlands. The highlands of east Africa are located where the southwesterly winds from the Atlantic and the southeasterly winds from the Indian Ocean converge in summer, bringing heavy thunderstorm activity to this area and rainfall to the Ethiopian highlands. Warm water bodies, such as Lake Victoria and the other large lakes of the Rift Valley, supply additional moisture into these storm systems of the ITCZ, enhancing the precipitation.

Central Africa

Rainfall and temperature patterns in Central Africa vary considerably. Rainfall is relatively high over the central and coastal parts of the subregion but tends to diminish and become more variable toward the north. In the semiarid zone of Cameroon and Chad, temperatures vary greatly during the day. The low-lying coastal forests experience little annual changes in temperature (26–28°C) because of the persistent clouds overcasting the forests. Temperatures in the high-relief mountains are lower (19–24°C) (UNEP 2002).

Some regions of central Africa are among the wettest in Africa, with more than 3,000 mm of ITCZ-driven rainfall throughout the year. Communities living in humid forest areas experience floods (UNEP 2002). However, other parts of the subregion experience droughts.

North Africa

Northern Africa receives only 7 percent of Africa's total precipitation, and rainfall is variable and unevenly distributed throughout the subregion. There is a strong contrast in terms of rainfall volume between the Mediterranean coast, a frontal rainfall area receiving up to 800 mm mean annual rainfall, and the Sahara region, which is very dry. Very little rainfall occurs in the Sahara as most of the moisture does not reach that far across the landmass. Rainfall in the north of the continent also varies throughout the year. While moving north of the equator, the ITCZ brings rains to northern Africa.

In north Africa, droughts are recurrent, but flash floods also happen as a result of brief downpours on eroded soils (UNEP 2002).

Figure D2 shows the climatic zones in Africa which closely correlate with the differences in average annual rainfall.

FIGURE D2 Climatic zones in Africa

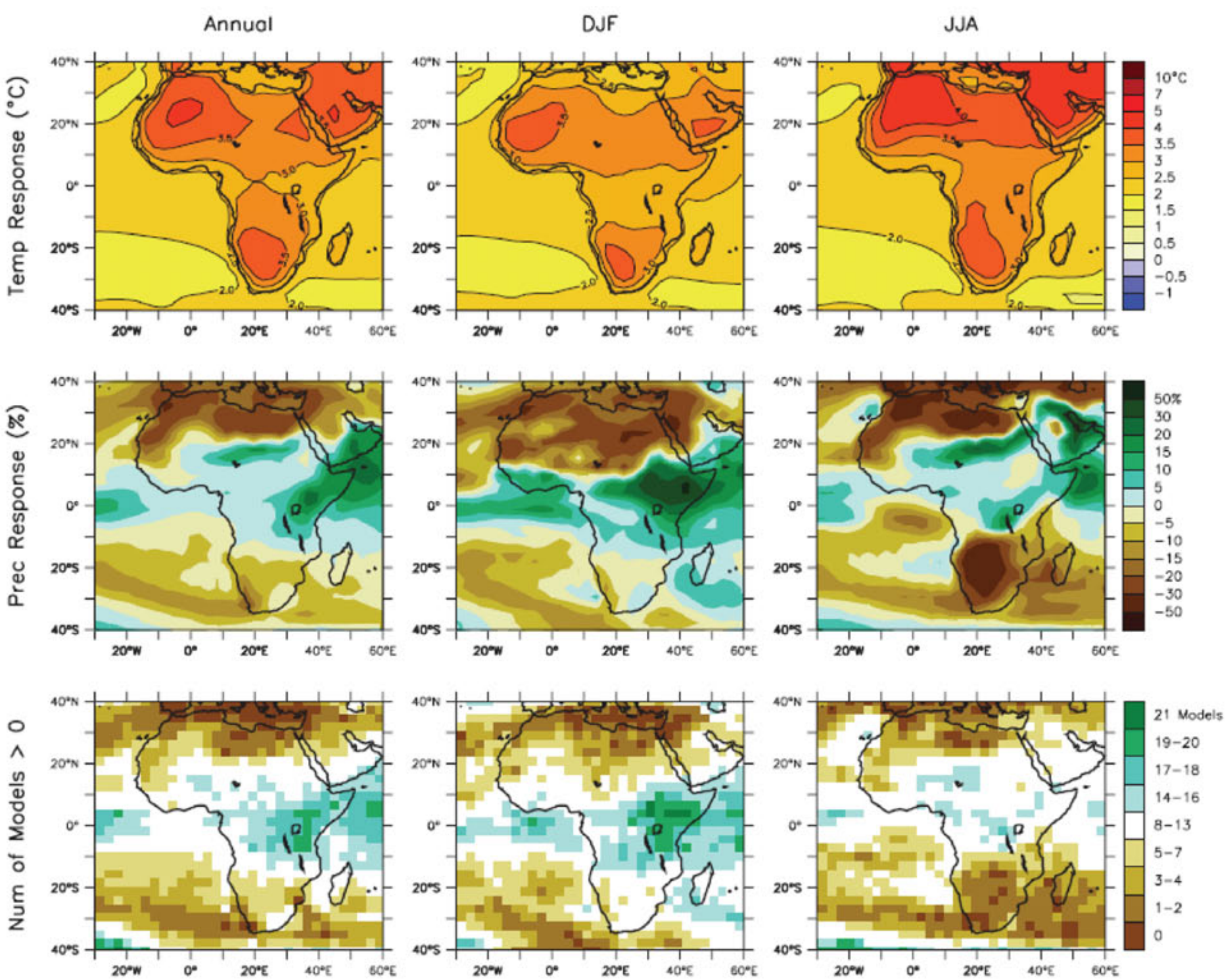
Source: World Book Encyclopedia 2009, in UNEP 2013.

2. Climate Change in Africa

Understanding the manifestation of climate change on the continent is complex and subject to uncertainty. The uncertainty in climate science arises from difficulties of modelling the complex and interrelated physical systems that drive climate, lack of data (incomplete knowledge on natural variability), unknown future greenhouse gas concentrations, and several 'unknown unknowns'. The IPCC recognizes that assessment across numerous models is required.

General Circulation Models (GCMs) provide the means for making global climate change projections. They are based on coarse data and therefore have limited applicability to local conditions. The emergence of downscaling and regional climate models (RCMs) is starting to provide more locally relevant climate predictions to enable local scale decision making. However, confidence in downscaled results is variable, and marked differences between downscaled future climates and the GCM predictions are observed. Climate modelling limitations imply that the focus of adaptation and management actions should be based on possible and plausible sets of vulnerabilities, and on adaptive ability, rather than the assumption of a single precise climate future. At the same time, downscaling of climate models to a scale that is more useful for decision making is needed.

FIGURE D3 Temperature and precipitation changes over Africa from the MMD-A18 simulations



Source: IPCC 2007a.

Note: Top row; Annual Mean, DJF (December, January, February) and JJA (June, July, August) temperature change between 1980–1999 and 2080–2099, averaged over 21 models. Middle row, same as top but for change in precipitation. Bottom row: number of models out of 21 that project increases in precipitation.

Despite the complexities and unknowns there is increasing certainty in some climate projections for Africa, with consensus between the major GCMs and the RCMs emerging on most parts of the continent. Global warming is strongly expected to increase climate variability in Sub-Saharan Africa (Euroconsult Mott MacDonald 2008). Climate change is also expected to bring about important variations in Africa's hydrological regimes, that is, the amount of annual rainfall, monthly distribution, geographical distribution in the region, evaporation rate, and run-off intensity (Cervigni, Liden, and Neumann 2015).

In Africa, climate change is expected to lead to a change in temperature, but also in rainfall and hydrology.

Increased temperature: Climate models concur that temperature increases are very likely in Africa during this century, with increases of 1–3°C by 2050 depending on the greenhouse gas emissions scenario. This warming is higher than the rest of the world and will be experienced across all seasons, with the continent's interior warming more than the coastal regions, and with increases in the drier subtropics greater than in the moist tropics. Temperatures are expected to steadily rise across the continent. In the first half of the century, temperature rise over Africa is slightly slower than the global average (a function of much of the continent being in the southern hemisphere, which is warming at a slower rate than the northern hemisphere).

However, by end-century the temperature rise over Africa is as high as and possibly in excess of the global average. Over the long term (2081–2100), an increase of 3–6°C is projected. The highest increases are expected to occur in Algeria, Mali, Niger, Sudan, Namibia, Angola, and Botswana. Equatorial and coastal areas will experience lower warming. Inland regions and the subtropical zones on the continent warm more than coastal belts. The rate of warming is projected to be the fastest in southern Africa, linked to future rainfall decreases in the region and therefore the diminished ability of soil to contribute to evaporative cooling. According to one analysis, in low-emission scenarios, by 2100, a third of the continent will likely shift into an altogether new climate regime due to extreme heat; in high-emission scenarios this is projected to occur over three-fourths of the continent (Serdeczny et al. 2016). Other studies paint a similar picture: in a world that is 2°C warmer (by the 2040s), roughly 45 percent of Africa's land area will experience unusual heat extremes in the summer, and 15 percent will experience unprecedented heat extremes. In a world that is 4°C warmer (by the 2080s), an estimated 85 percent of the continent's landmass will exhibit unusual heat extremes in summer months, and more than half will undergo unprecedented heat extremes (World Bank 2013).[14] Higher temperatures of this nature mean warmer waters and more evaporation. As warmer air holds more moisture, this begins to alter the hydrological cycle.

Temperature rise is already being observed across Africa. The IPCC (2007a) documented a warming trend across the African continent since the 1960s, with decadal warming rates of 0.29°C in the tropical forests and 0.1–0.3°C in southern Africa (with some anomalies of decreasing temperatures detected in eastern Africa near the coast and the inland lakes). The IPCC's AR5 of 2014 documented an observed temperature increase of 0.4–2.25°C in the region (above preindustrial levels), with most of the warming having occurred in western Sahara, Mauritania, Mali, and Niger.

Altered rainfall: Most other climate impacts on Africa's water resources are driven by changes in precipitation patterns. Future projections of rainfall variation are variable, although consensus is emerging for a decreased mean annual rainfall in much of Mediterranean Africa and the northern Sahara. Similarly, rainfall in southern Africa is likely to decrease in the southwest and on the western margins. These rainfall decreases are in the winter rainfall regions. Given that these regions are currently on the fringes of the frontal rain belt, a slight poleward displacement of these systems will result in the fronts passing to the south and north of African landfall, resulting in less rain falling on the land itself.

In eastern Africa, there is likely to be an increase in mean annual rainfall, owing to the increased intensity of convergence in this area between December and February, and more moisture being brought in off the Indian Ocean. The topography of the area will also generally result in increased rainfall, as the highlands force this moisture-laden air up into the atmosphere.

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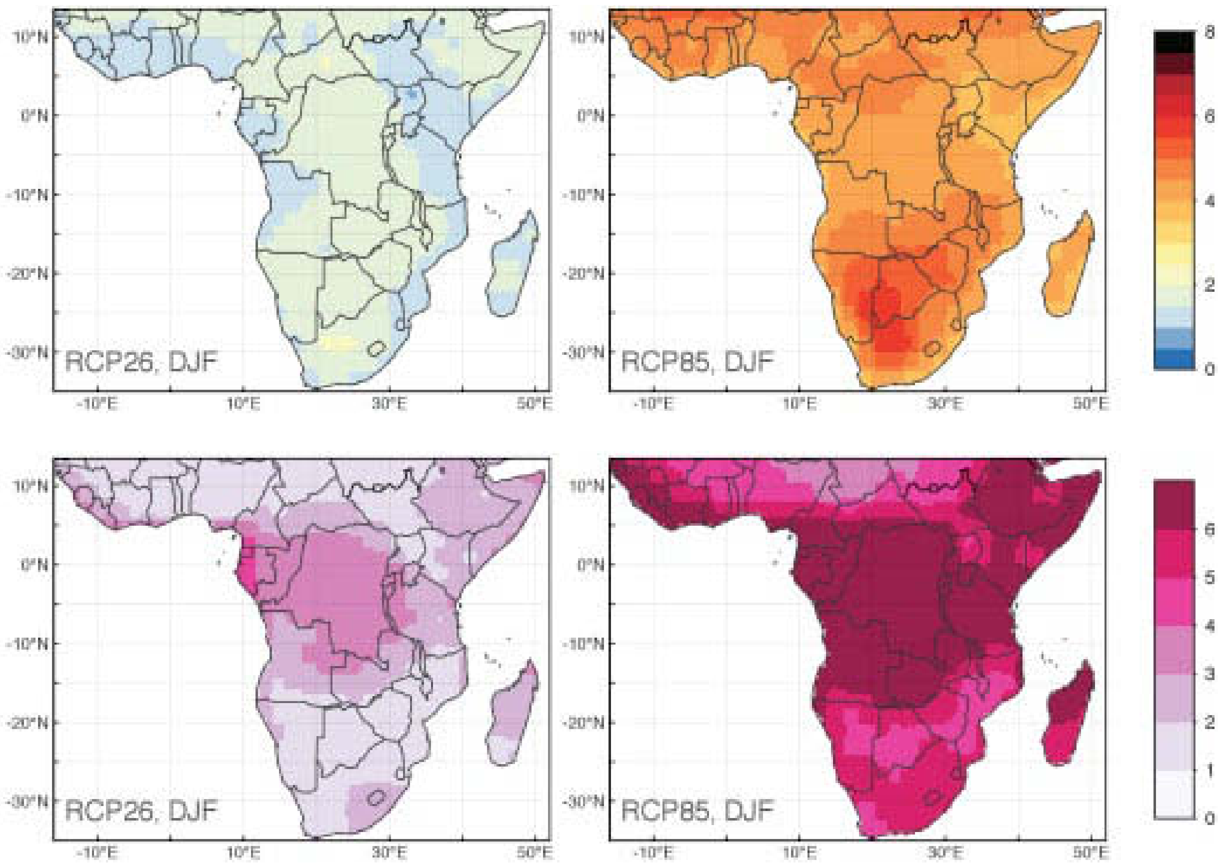
14 In the report cited, 'unusual' and 'unprecedented' heat extremes are defined by using thresholds based on the historical variability of the current local climate. "The threshold depends on the natural year-to-year variability in the base period (1951–1980), which is captured by the standard deviation (sigma). Unusual heat extremes are defined as 3-sigma events (meaning warming is three times as great as historical variability). For a normal distribution, 3-sigma events have a return time of 740 years. The 2012 U.S. heat wave and the 2010 Russian heat wave classified as 3-sigma events. Unprecedented heat extremes are defined as 5-sigma events (where warming is five times as great as historical variability). They have a return time of several million years. These events which have almost certainly never occurred to date are projected for the coming decades."

FIGURE D4 Multi-model temperature anomalies in summer months



Source: World Bank 2013.

Note: For Representative Concentration Pathway (RCP) scenarios 2.6 and 8.5 (for 2071–2099), indicating the standard deviation of temperature from the norm (in degrees C).

In the medium term (2046–2065), there will likely be a 20 percent decrease in wet season (December to February) precipitation across much of the already dry northern and southern portions of the region, with a potential increase in precipitation of up to 50 percent in east Africa during the wet season. These effects are anticipated to be enhanced over the long term (2081–2100) over the dry northwestern region with a 50 percent decrease in precipitation over December to February. The IPCC (AR5) projects a 10–50 percent increase in precipitation in the northeast part of the continent including Egypt, Sudan, and Chad and a 50 percent decrease mostly on the relatively dry southwestern region (Namibia, Angola, Botswana, Zambia, and South Africa).

There is increasing consensus that rainfall events will become more intense, as the energy in the atmospheric system increases and greater amounts of moisture are transported in the air, and will manifest in intensity of tropical cyclones of the Indian Ocean. However, the effects on the frequency of the cyclones, and the likelihood of them hitting the land, remain uncertain. There is the potential for increased flooding in areas where rainfall is likely to increase and the combination of increased flooding and sea level rise puts the coastal areas of eastern Africa and on the south coast of the bulge of Africa particularly at risk.

However, much uncertainty exists in climate projections for the remaining areas and seasons of Africa. Even within the areas outlined above, significant variations may exist when models are rescaled to the regional or subregional level, and the impacts of localized effects driven by local topographic conditions or vegetation feedbacks remain uncertain. These effects can be significant, as they often occur in high rainfall headwater catchments that generate the bulk of the runoff.

3. Implications of Climate Change for Water Resources

The climate influences water resources in two ways; first, the amount and frequency of rainfall impacts the runoff and recharge of a water body; moreover, other climatic factors such as temperature, wind, and humidity influence both the rates of evapotranspiration of the water resources, but also the demands on the resource (Water Research Commission 2009).

As listed by the UNEP, climate change can have the following consequences:

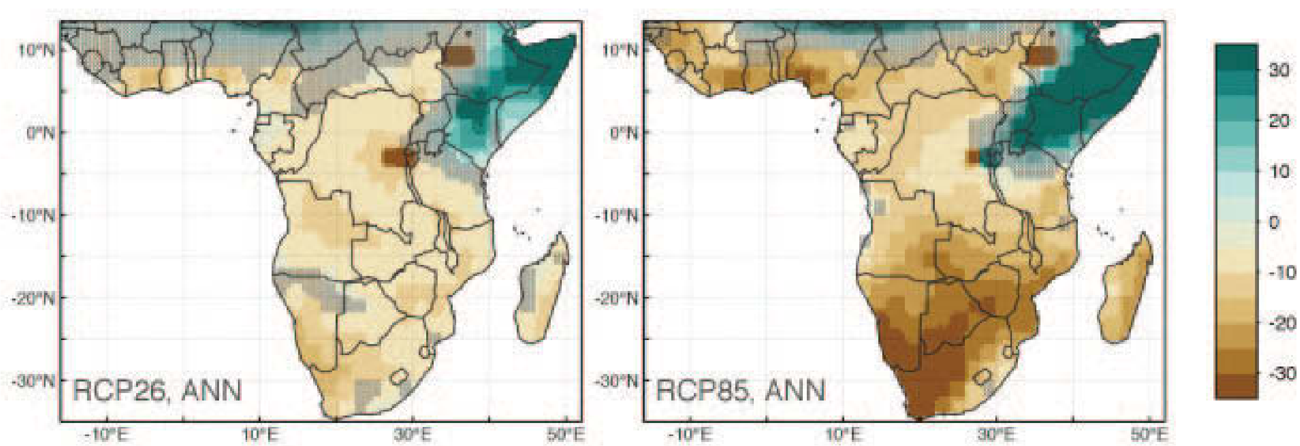
- changes in mean annual rainfall change runoff (MAR) and system yields;
- changes in the onset of rain affect the duration and timing of low and high flow periods;
- changes in the intensity of rainfall events change flood patterns and groundwater recharge;
- changes in variability affect the return period of droughts, requiring additional storage where this return period is increased;
- water demand patterns may change because of changing temperature and humidity regimes; and
- diversification of water resources and conjunctive use may become more widespread as uncertainty increases (Water Research Commission 2009).

The modification of these climate-water dynamics can require profound shifts in resource management. Planning is made difficult by the uncertainties created by climate change, and historical data cannot always inform future decisions, but for the trends they show. Resource management should thus be increasingly flexible and adaptive. Thus, the planning and management of water resources requires the consideration of many uncertainties, including the extent and nature of future requirements, and the inaccuracy of our knowledge of both rainfall and runoff (Water Research Commission 2009).

Most scientific studies forecast that climate change's impact on water resources in Africa will manifest in four main trends: toward aridity, more frequent and prolonged droughts, more frequent and intense floods, and finally toward increasing variability. However, this forecast for Africa is characterized by deep uncertainty.

Trend toward aridity: The levels of aridity of Africa will be defined by the temperature and rainfall patterns on the continent. Arid regions are those which exhibit a long-term structural deficit between total annual rainfall and total evapotranspiration (unlike drought-affected regions, which experience a temporary period of dryness). In other words, these are regions where there the water received is less than the water lost to the atmosphere, making the land dry. Since evapotranspiration rates are primarily driven by warmth, rising temperatures in Africa are likely to raise evapotranspiration levels. Climate models demonstrate a largely increasing trend for evapotranspiration

FIGURE D5 Multi-model mean of the percentage change in the Aridity Index



In non-hatched areas, at least 4/5 (80 percent) of models agree. In hatched area, 2/5 of the models disagree. Note that a negative change corresponds to a shift to more arid conditions. Particular uncertainty remains for East Africa, where regional climate model projections tend to show an increase in precipitation which would be associated with a decrease in the Aridity Index (see also footnote 2). A decrease in aridity does not necessarily imply more favorable conditions for agriculture or livestock, as it may be associated with increased flood risks.

Source: Serdeczny et al. 2016.

Note: In a 2°C world (left) and 4°C world (right) for Sub-Saharan Africa by 2071–2099 relative to 1951–1980.

across Sub-Saharan Africa (with some inconsistencies in parts of east Africa, where potential increases in rainfall may offset evaporative loss). The trend toward aridity is most significant in southern Africa, and particularly in southwestern Africa, where projections suggest reduced rainfall (Serdeczny et al. 2016).

Depending on the level of temperature rise in the coming decades, aridity will become increasingly pronounced. Recent studies suggest that in a world that warms by 2°C (expected by the 2040s), arid and hyper-arid regions in Sub-Saharan Africa will grow by at least 3 percent, and that in a world that is 4°C warmer (expected by the 2080s based on the current trajectory), Sub-Saharan Africa will see a 10 percent increase in arid and hyper-arid regions, that is, in as much as a tenth of its area (World Bank 2013). The implication for river basins is clear: as Sub-Saharan Africa gets drier, water availability in its hydrological systems will decline.

More frequent and prolonged droughts: Drought conditions arise when there are prolonged periods without rainfall. The increase in aridity will be a key driver of droughts in the continent. Climate change is expected to increase the occurrence and severity of droughts in many parts of Sub-Saharan Africa, particularly southern Africa. Under scenarios of 2°C warming (by the 2040s), studies warn of the risk of severe drought in both central and southern Africa, and of elevated drought risk in western Africa. The ramifications of a 4°C rise in temperature are even more serious, creating a very likely risk of extreme drought in southern Africa, severe drought in central Africa, and increased risk in west Africa.

More frequent and intense floods: While flooding is already a feature of Africa's natural climate variability (including the ENSO system), climate change is expected to exacerbate flooding in several parts of Africa. Across the Horn of Africa, projections point to an increase in rainfall volume during the high rainfall months, suggesting more heavy and intense rainfall events that will likely trigger heavier flooding (World Bank 2013). Mean annual flows and low flows in certain river systems are projected to increase with climate change (due to increases in rainfall), such as the Blue Nile Basin and the Niger Basin, elevating future flood risk in these rivers.

Increasing variability (interannual and seasonal): Africa is already characterized by strong interannual and inter-seasonal climate variability. This is even more so for rainfall than for temperature. Some studies have found that at the continental scale, changes in rainfall volume (annual and decadal) are not as significant as the changes in temporal distribution, that is, time periods within which the rain falls. Particularly debilitating multi-decadal rainfall variability is also observed in the Sahel (Serdeczny et al. 2016). Climate variability in eastern and southern Africa in particular is impacted by the ENSO system, strongly implicated in both floods and droughts in these regions (World Bank 2013). While there is still deep uncertainty about the impact (if any) that manmade climate change is having on ENSO, recent findings support the possibility that the *impacts* of ENSO are worsened by climate change, even though ENSO itself is unchanged. In other words, because of a warmer atmosphere that carries more moisture, the playing conditions in which ENSO operates are being altered (Stevenson and Fox-Kemper n.d.). Emerging science also suggests that climate change may be making large, extreme ENSO events more frequent (Cai, Borlace, and Lengaigne 2015). For parts of Africa that already feel the impact of ENSO cycles—especially eastern and southern Africa—this could mean more frequent, or more intense mega-droughts and mega-floods.

Deep uncertainty across all the above impacts: For much of Africa, long-term historical trends are difficult to identify due to a paucity of data and longitudinal records. This creates challenges for determining the historical norm or baseline against which to assess future climate change. Uncertainty remains large for future rainfall projects across the continent, but especially so for east Africa where RCMs do not concur with global circulation models regarding the increasing rainfall trend in the future (World Bank 2013). Uncertainty constrains decision making, including about water resources planning and management.

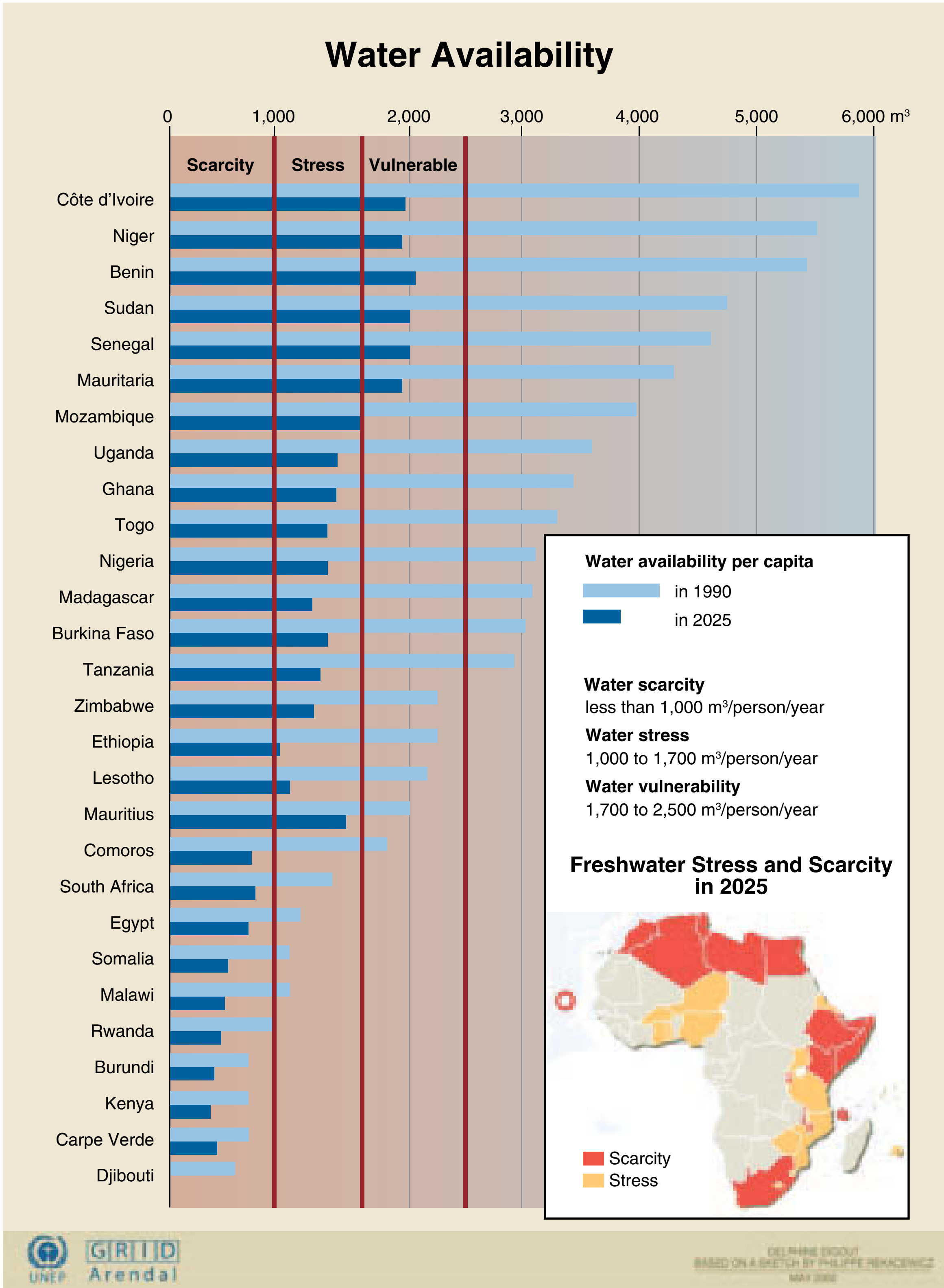
4. Exposure to Climate Stressors and Shocks

Climate change impacts the society and the economy in a multitude of ways, through increased water stress and scarcity, as well as increased disasters frequency and intensity. In the following, we will review those two important factors and how they lead to an increased exposure of people, as well as of manmade and natural infrastructure.

A. Unreliable supply (availability)

As seen in section two of this annex, *Climate Change in Africa*, climate change increases the unreliability of rainfall and flows across the African continent. In certain parts of Africa, rainfall is expected to decrease, and so will the water levels and flow.

FIGURE D6 Levels of water stress over time in select African countries



Source: UNECA 2000.

Unreliable supply impacts the economy and livelihoods of individuals within African water basins. Unpredictability and unreliability make it difficult for industries to plan for levels of water input and resulting economic output. It also makes it difficult for communities, especially those depending on rain-fed agriculture and grazing, to plan time for harvesting, and so on.

Further, in the region that will get drier due to climate change, current availability problems are likely to be exacerbated by further decreasing the water supply.

The availability of surface and groundwater across Africa varies geographically, as the northern and southern ends of the continent and the Horn are arid, while the middle third of the continent is relatively wet (International Finance Cooperation 2011). Water availability is also linked to the volume of water that can be stored per capita. This storing volume capacity minimizes the sensitivity of a region to changing levels of water supply throughout the year or throughout a couple of years, and help coping with dry months or years.

As a whole, Africa has underdeveloped water storage infrastructure, with the exception of South Africa. Groundwater acts as natural storage, and although the underground resource represents only 15 percent of the water resource on the continent, it supplies about 75 percent of the population with most of their drinking water (UNEP 2010). Water towers, that is, forested upland areas which are often transnational, also act as storage, thereby playing an important supply role.

Africa is thus vulnerable to unreliable supply due to a lack of storage infrastructure. In addition, the water supply is affected by human use, and it is pressured by increasing demand from a growing population and developing economy.

Water availability is intrinsically linked to quality. Human activities on the basin indeed affect the quality and thus the reliability of the water supply in the basin. For example, land degradation can lead to high levels of turbidity,[15] poor agricultural practices contribute to eutrophication,[16] and poor sanitation and solid waste management can result in high pollution levels in the water resource. Agricultural production, mining, and other industries, as well as the extension of urban areas, also put pressure on and degrade wetlands. Finally, water towers are also threatened by deforestation.

Turning to the demand, as seen under the Demographic subsection in Annex C, population growth in Africa is high, especially in west, central, and eastern Africa, where population growth rates are estimated to be over 2.5 percent yearly. This increasing demand represents an increased pressure on the water resources in Africa. Regions that are prone to episodes of water scarcity such as east Africa are likely to be increasingly vulnerable as a result of climate change.

To conclude, climate stressors impacting the availability of water are a burden, putting pressure on an increasingly demanded water resource. Climate stressors leading to an unreliable supply are likely to exacerbate food shortages in Africa.

B. Repeated disasters

Large-scale and repeated disasters represent considerable shocks and stresses to the communities living in water basins in Africa, as well as to the economy operating in those areas. As discussed above, climate change is expected to increase the frequency and intensity of disasters in numerous regions in Africa. Climate is a major factor in triggering natural disasters in Africa; indeed, according to the UN Office for the Coordination of Humanitarian Affairs (UNOCHA) Africa, out of 104 natural disasters reported in 2008, 99 percent were climate related. These disasters affected 16.7 million people (Water Research Commission 2009).

Climate change materializing through disasters impact not only the economy and infrastructure, but also the livelihoods and health of communities. Disasters impact the development of crops and of livestock. Floods bring diseases, droughts, and malnutrition. Climate change and disasters also impact the migration flows, and people's ability to find a shelter and decent conditions of living (Water Research Commission 2009).

15 That is, muddiness created by stirring up sediment or having foreign particles suspended.

16 That is, water bodies receive excess nutrients from pollution and runoff that stimulate excessive plant growth.

5. The Consequences of Climate Change and Climate-Change-Induced Water Shocks and Stresses on Development Trajectories

The impact of climate change goes beyond its effects on hydro-climatology and water availability, to impact the development trajectories of communities, nations, basins, and regions. Climate change can thus be said to have effects on the physical environment, but also indirectly on the political, social, and economic spheres (Water Research Commission 2009).

The impacts of climate change on the availability of water and on the frequency and intensity of disasters affect the agricultural production, the power industry, and even urban and industrial activity. In the worst-case scenario, climate change leads to falling production, as well as reduced productivity and competitiveness (Water Research Commission 2009). Climate change can thus jeopardize economic growth and development. Moreover, climate change puts particular pressure on the most vulnerable communities, which are usually already the poorest (poor communities are usually both more exposed and sensitive to climate change).

Climate change is thus an obstacle on Africa's path to achieve a multitude of Sustainable Development Goals (SDGs). In the framework of our study on the importance of cooperation on transboundary water basins to build resilience in the face of climate change, at least 10 SDGs are of high importance,[17] and are general goals that are affected by the effect of climate change on water bodies across the African continent. Such impact can be direct or indirect, via intermediate factors.

To conclude, climate change and climate-change-induced water shocks and stresses are another factor playing in the development of the African continent. It is a challenge to be added to the demographic growth and shift which pressure water resources. Increasing the resilience to climate change of populations and of the economy is an item to put high on the priority list of African governments, together with development goals.

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17 The following SDGs are particularly important to consider: ending poverty (SDG1); ending hunger (SDG2); ensuring healthy lives and promoting well-being (SDG3); ensuring availability and sustainable management of clean water and sanitation (SDG6); ensuring access to affordable, reliable, sustainable, and modern energy (SDG7); promoting sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work (SDG8); building resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation (SDG9); making cities and human settlements inclusive, safe, resilient, and sustainable (SDG11); taking urgent actions to combat climate change and its impacts (SDG13); protecting, restoring, and promoting sustainable use of terrestrial ecosystems, sustainably managing forests, combating desertification, and halting and reversing land degradation and halting biodiversity loss (SGD15). For more details on sub-goals of each category on Millennium Development Goal (MDG), see the UN website on SDGs at: https://sustainabledevelopment.un.org/?menu=1300.

E Characteristics of Resilience and Associated Water Management Systems

Preparedness: Preparedness is the capacity to anticipate events, to be prepared to manage and cope with shocks and change. Being prepared means having analyzed a variety of scenarios, and being ready to act upon the materialization of one of these. Preparedness is thus a key characteristic of resilience, to anticipate shocks and stresses, and to build the capacity to respond to it. For example, in case of disasters, preparedness allows communities to cope with the disasters, and the government to have in place a strategy for quick and cost-effective disaster responses. Rapid responses post-disasters are key for society to rebuild quickly. Preparedness thus allows socioeconomic systems to react to climate events in an appropriate manner, and to minimize the impact of such events in the short, medium, and long run. Water management systems to enhance preparedness include flood forecasting systems, early warning systems, emergency response plans, and/or flood protection plans; it also includes reflecting upon urban planning and development, building storage capacity, developing appropriate operating rules, managing land use and watershed, as well as preserving national infrastructure.

Robustness: Robustness is the ability of the system to withstand shocks and stresses, even when adequate information is not available and future events are not fully understood. This requires systems that are designed and operated to withstand extreme events, as well as to be able to function effectively under alternative futures. Systems that reinforce the robustness of water systems include the storage that is designed for assurance of supply and climate variability, flood protection infrastructure that considers alternative climate futures, operating systems that can respond to extreme events and changing circumstances, institutional cooperation that enables coordinated response to shocks by disparate groups, local community capacity to withstand shocks through alternative water-dependent livelihoods, and information systems that inform decision makers about changing conditions.

Adaptability: Adaptability is the capacity to modify responses as the system changes. Being adaptable is thus being attentive and responsive to external changes. This requires inherent flexibility within the infrastructure and institutional systems, all supported by appropriate information about changing circumstances. The adaptability of water systems is reinforced by adopting flexible institutional arrangements, flexible water storage and infrastructure design, as well as responsive FRM strategies. Importantly, adaptability is strengthened by designs that allow alternative operating regimes that are appropriate under alternative development and climate futures. Adaptability is also built through policies that facilitate appropriate technology adoptions and climate smart actions, and enable the strengthening of alternative local livelihoods.

Diversity and redundancy: Diversity is key to resilient socioeconomic systems, as it helps ensure that the system does not rely on a single parameter to survive and thrive. Diversification helps decrease the exposure of a systems to specific shocks and stresses, and thereby its vulnerability. Redundancy, in this context, means that extra capacity is present in a system to create some leeway and decrease the exposure to specific shocks and stresses, which is particularly relevant in a context of climate variability and change. For example, diversity in energy sources and redundancy in the available capacity to create energy are two key characteristics to the economic resilience and socioeconomic development, particularly where hydropower of thermal energy generation is dependent upon variable and changing water resources. The costs of this 'redundant' capacity, which is underutilized under 'average' conditions, may be outweighed by the benefit gained when additional production capacity is needed, in 'extreme' situations. Increasing diversity and redundancy of water systems may include the construction of storages in cascade, linked infrastructure systems that access water from different climate regimes, operating rules that allocate water at different assurance of supply, cooperation through regional power pools, the diversification of water and energy supply sources, the diversification of crops and irrigations practices, institutional capacity and systems that can function even when a part of the system fails, and shared information systems that depend upon multiple sources.

Integration and connectedness: Integration and interconnectedness between elements of a system and the actors involved in its management are other key characteristics of resilience. It allows the sharing of necessary information to have a holistic understanding of the river basin. It also helps decision makers cooperate in the response to events, efficiently produce benefits from the river, or to develop water resources in a coherent manner. Systems that build resilience through connectedness include coordinating hydropower generation between facilities, including through regional power pools; conjunctive use of surface and groundwater; and interconnected water storage systems with coordinated operating rules. It also includes planning interventions and strategies at a basin level with key role players, advancing multipurpose infrastructure, and integrating natural and built infrastructure in strategies, as well as working toward water-related policy harmonization. Institutional cooperation and shared information systems are also critical to enabling the flow of information to enable appropriate responses to systemic shocks and stresses, as well as changing circumstances.

Transformability: Transformability is the capacity of a system to change itself and adapt, as required by changes of shifts in the external environment or events. On the one hand, this requires the availability of resources and capability to explicitly make changes, whether proactively or responsively. On the other hand, it requires that the system is able to change and is not locked into a specific paradigm or operating regime. Thus, transformability requires that as far as possible, future options and alternatives are not foreclosed or limited by current or historical decisions. Transformability in water systems is enabled by flexible policy and legislative measures, strategies that are reviewed and revised within a longer term vision, infrastructure systems that can be physically altered or operated in different ways, and management institutions that can learn and reorganize as conditions change. Furthermore, transformability is dependent upon the building of resources at community and national levels that provide people and countries with the capability to make changes as they are needed, because lack of resources is a huge impediment to transforming systems.

It is important to note that all the water systems referred to in the preceding discussion of resilience may be categorized broadly as related to information, institutions, or infrastructure, or what may be referred to as the 3 I's. The argument in this report is that these 3 I's are the platform upon which water-related resilience is built. However, it should also be noted that all the above mentioned characteristics, and transformability in particular, require adequate human and financial resources at community and national levels to enable them to be effectively implemented. Importantly, it is by effectively managing the benefits from water systems that these resources can be developed over time.

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