



USAID
FROM THE AMERICAN PEOPLE

CLIMATE CHANGE AND WATER RESOURCES IN WEST AFRICA: TRANSBOUNDARY RIVER BASINS

AUGUST 2013

This report is made possible by the support of the American people through the U.S. Agency for International Development (USAID). The contents are the sole responsibility of Tetra Tech ARD and do not necessarily reflect the views of USAID or the U.S. Government.



ARCC



African and Latin American
Resilience to Climate Change Project

Contributors to this report, in alphabetical order, are Audra El Vilaly and Mohamed Abd salam El Vilaly of the University of Arizona through subcontract to Tetra Tech ARD.

Cover Photo: International Center for Tropical Agriculture (CIAT)

This publication was produced for the United States Agency for International Development by Tetra Tech ARD, through a Task Order under the Prosperity, Livelihoods, and Conserving Ecosystems (PLACE) Indefinite Quantity Contract Core Task Order (USAID Contract No. AID-EPP-I-00-06-00008, Order Number AID-OAA-TO-11-00064).

Tetra Tech ARD Contacts:

Cary Farley, Ph.D.

Chief of Party

African and Latin American Resilience to Climate Change (ARCC)

Burlington, Vermont

Tel.: 802.658.3890

Patricia.Caffrey@tetratech.com

Anna Farmer

Project Manager

Burlington, Vermont

Tel.: 802.658.3890

Anna.Farmer@tetratech.com

CLIMATE CHANGE AND WATER RESOURCES IN WEST AFRICA:
TRANSBOUNDARY RIVER BASINS

AFRICAN AND LATIN AMERICAN RESILIENCE TO CLIMATE CHANGE (ARCC)

AUGUST 2013

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS	IV
ABOUT THIS SERIES	VI
EXECUTIVE SUMMARY	VII
1.0 INTRODUCTION	I
1.1 PURPOSE	I
1.2 ANALYTICAL FRAMEWORKS	I
2.0 BACKGROUND AND CONTEXT	3
2.1 PRESENTATION OF TRANSBOUNDARY RIVER BASINS IN WEST AFRICA AND THEIR MANAGEMENT INSTITUTIONS	3
2.2 DAMS	12
2.3 RELIANCE ON RIVER BASINS	13
2.4 FUNDED PROJECTS	14
3.0 CLIMATE IMPACTS ON TRANSBOUNDARY RIVER BASINS	16
3.1 CLIMATE AND FRESHWATER RESOURCES	16
3.2 PRECIPITATION AND SURFACE WATER SUPPLY	19
3.3 TEMPERATURE AND SURFACE WATER SUPPLY	27
3.4 EXTREME CLIMATE EVENTS	28
3.5 CLIMATE AND WATER QUALITY	29
3.6 CLIMATE CHANGE AND RIVER ECOSYSTEMS	30
3.7 CONCLUSIONS	31
4.0 CLIMATE IMPACTS ON RIVER BASIN-DEPENDENT LIVELIHOODS AND INDUSTRIES	33
4.1 CLIMATE CHANGE AND RIVER BASIN PRODUCTION	33
4.2 CLIMATE CHANGE AND RIVER-LINKED LIVELIHOOD STRATEGIES	35
4.3 CLIMATE CHANGE AND RIVER-LINKED INDUSTRIES AND INFRASTRUCTURE	35
4.4 DISASTER RISK REDUCTION AND MANAGEMENT	39
4.5 CONCLUSIONS	41
5.0 ADAPTIVE CAPACITY OF INSTITUTIONS	42

5.1 ASSESSING ADAPTIVE CAPACITY	42
5.2 NIGER BASIN AUTHORITY (NBA).....	43
5.3 SENEGAL RIVER BASIN DEVELOPMENT AUTHORITY (OMVS)	44
5.4 VOLTA BASIN AUTHORITY (VBA)	48
5.5 LAKE CHAD BASIN COMMISSION (LCBC)	49
5.6 GAMBIA RIVER BASIN DEVELOPMENT ORGANIZATION (OMVG).....	53
6.0 CONCLUSIONS	55
6.1 CLIMATE CHANGE IMPACTS ON RIVER BASINS AND WATER SUPPLY	55
6.2 KNOWLEDGE GAPS	55
6.3 PRIORITIES FOR FUTURE RESEARCH	56
7.0 ANNEXES.....	60
ANNEX A: PROPOSED RESEARCH PLAN	61
ANNEX B: AVAILABLE MAPPING RESOURCES FOR WEST AFRICAN TRANSBOUNDARY RIVER BASINS	71
ANNEX C: IMPACTS OF CLIMATE CHANGE ON AGRICULTURAL PRODUCTION... 	75
8.0 REFERENCES.....	77

ACRONYMS AND ABBREVIATIONS

ACIA	Adaptive Capacity Institutional Assessment
ACW	Adaptive Capacity Wheel
ADB	African Development Bank
AEJ	African Easterly Jet
ANBO	African Network of Basin Organizations
AON	African Online News
BGR	Federal Institute for Geosciences and Natural Resources
CACG	Compagnie d'Aménagement des Coteaux de Gascogne
CIDA	Canadian International Development Agency
CV	Coefficient of Variation
EC	European Commission
ECOWAS	Economic Organization of West African States
EPA	(United States) Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FCFA	West African CFA franc and Central African CFA franc (currencies)
GCM	General Circulation Model
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GIWA	Global International Waters Assessment
GIZ	German Society for International Cooperation (Deutsche Gesellschaft fuer international Zusammenarbeit)
ICT	Information and Communications Technology
IEG	Independent Evaluation Group
IFAD	International Fund for Agricultural Development
IIED	International Institute for Environment and Development
IRD	Institut pour la recherche du développement
ITCZ	Inter-Tropical Convergence Zone
IUCNNR	International Union for Conservation of Nature and Natural Resources

IWLP	International Water Law Project
LCBC	Lake Chad Basin Commission
MAD	Mean Annual Discharge
MAR	Mean Annual Runoff
MODIS	Moderate Resolution Imaging Spectroradiometer
MT	Metric Tons
NAPA	National Adaptation Plan of Action
NASA	National Aeronautics and Space Administration
NBA	Niger River Basin
OECD	Organisation for Economic Co-operation and Development
OMVG	Gambia River Basin Development Authority (Organisation pour la mise en valeur du fleuve Gambie)
OMVS	Senegal River Basin Development Authority (Organisation pour la mise en valeur du fleuve Sénégal)
PACN	Pan Africa Chemistry Network
SOGED	Société de Gestion et d'Exploitation de Diama (Diama Dam Management Company)
SOGEM	Société de Gestion de l'Energie de Manantali (the Manantali Energy Management Company)
SPM	Sedentary Pasture Management
SST	Sea-Surface Temperature
TRB	Transboundary river basins
TRBMI	Transboundary River Basin Management Institution
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Programme
UNHCR	United Nation High Commissioner for Refugees
USAID	United States Agency for International Development
USGS	United States Geological Survey
VBA	Volta Basin Authority
WAM	West African Monsoon
WMO	World Meteorological Organization
WWF	World Wide Fund for Nature

ABOUT THIS SERIES

THE STUDIES ON CLIMATE CHANGE VULNERABILITY AND ADAPTATION IN WEST AFRICA

This document is part of a series of studies produced by the African and Latin American Resilience to Climate Change (ARCC) project that addresses adaptation to climate change in West Africa. Within the ARCC West Africa studies, this document falls in the subseries Climate Change and Water Resources in West Africa. ARCC has also developed subseries on Agricultural Adaptation to Climate Change in the Sahel, Climate Change and Conflict in West Africa, and Climate Change in Mali.

THE SUBSERIES ON CLIMATE CHANGE AND WATER RESOURCES

Upon the request of the United States Agency for International Development (USAID), ARCC undertook the West Africa water studies to increase understanding of the potential impacts of climate change on water resources in West Africa and identify means to support adaptation to these changes. Other documents in the Climate Change and Water Resources in West Africa series include Coastal Vulnerability Maps, Coastal Biophysical and Institutional Analysis, and an Assessment of Groundwater Management.

EXECUTIVE SUMMARY

The present desk study aims to clarify the impacts of climate change on transboundary river basins (TRBs) in comparison to other stressors, and to offer an initial web-based assessment of the adaptive capacity of Transboundary River Basin Management Institutions (TRBMIs) in West Africa. The purpose of this study is to serve as a basis for further research related to the design of activities reinforcing the capacity of these institutions to sustainably develop and protect river basin resources, ecosystems, and livelihoods in the face of climate change.

There are 11 major TRBs in West Africa. They range in size from 2,113,350 km² (Lake Chad Basin) to 16,000 km² (Tanoé River Basin). To date, there are only five transboundary river basin authorities in the region. Each country in the region, with the exception of Cape Verde, shares at least one river with at least one other country. Much of the water resources of individual West African nations are sourced from outside these nations, which makes equitable resource allocation and cooperation between upstream and downstream users a primary concern.

Water resource stress and scarcity are on the rise in West Africa. Current total freshwater withdrawal in West Africa for agriculture, industry, and domestic uses combined is expected to triple by 2025. There are many non-climate stressors on TRBs in West Africa, including population and economic growth, poor water management and infrastructure, inefficient water provision, inadequate joint management of basin resources, declines in groundwater, and land use/land cover changes.

This desk study demonstrates that by 2030-2050, changes in temperature and precipitation due to climate change will have variable impacts on surface water levels in different areas of the region. In general, river basins and their water supplies will be most vulnerable to climate change in the Sahel, and particularly in the Western Sahel, which will see higher temperatures and lower precipitation by the mid-century. This area includes the Senegal, Gambia, western Niger, and Upper Volta River Basins.

During the last half-century, West Africa's rivers have experienced an overall decline in water supply. Climate variability and change, in addition to the stressors mentioned above, are expected to further reduce river basin water supply in the future. Based on climate projections alone, river flows are expected to decline by 15-20 percent for 2020 and by 20-40 percent for 2050 (CIFOR 2005).

The climate variable with the most direct influence on water supply is precipitation. For the region as a whole, reductions in precipitation have been accompanied by declines in runoff; however, at the sub-regional level, the relationships between precipitation, runoff, and discharge are complex and are expected to remain so in the future. Indeed, a high level of uncertainty persists in regard to the amount of runoff and discharge the region will experience. In general, there is a nonlinear relationship between climate and the availability of freshwater resources in the TRBs of West Africa, which is based both on the historical record and future projections. This finding is caused by compounding variables, most notably the biophysical underpinnings of land use/land cover change. As such, climate is not the single or even most important factor in determining water supply in West Africa.

Climate change has and will continue to threaten socioeconomic water-dependent activities in West Africa, including farming, livestock production, and fishing. For the region as a whole, food production is expected to decrease, though it may vary on the sub-regional level. Irrigation is still an underexploited technology, with only 5 percent of the total region's area benefiting from it. Recently, inland fishing has seen lower catch rates, but like the other changes documented here, these rates cannot be attributed

solely to climate. Population growth, dam technology, extraction rates, invasive species, among other factors, also contribute to this phenomenon.

West Africans are adopting numerous adaptation and coping measures in light of climate change and many other socioeconomic, political, and environmental factors. These measures should be understood in terms of their accessibility to different populations, as well as their trade-offs and potential impacts on water supplies. Moreover, climate change is expected to alter river-linked value chains, especially in terms of production, marketing, and distribution of agricultural and fishing goods. Climate change is additionally expected to compromise the function of hydroelectric dams in the region. Floods are on the rise in West Africa, and improved systems for prediction, management, and response are needed. Furthermore, climate variability and change contribute to the dislocation of populations dependent on river systems in West Africa; though again, other factors are also to blame. Links between conflict and climate change-related resource scarcity are indirect, and care should be taken before attributing the former to the latter. Lastly, it is difficult, if not impossible, to isolate climate from the many other exacerbating factors driving socioeconomic changes related to water demand in the region.

This paper presents an initial, web-based assessment of the capacity of the five formal transboundary river basin management institutions (TRBMIs) in West Africa to promote climate change adaptation. The general scarcity of literature on these institutions limits the precision of the assessment, which, in the end, may reflect differences in the web presences as much as or more than the true nature of these institutions. The study proposes on site research to address this weakness and refine or disprove these initial findings.

High degrees of inconsistency and uncertainty still affect the relationship between climate and water supply. A host of exacerbating factors add to this uncertainty, including population growth, increased demand for hydropower and irrigation, and land use/land cover change. We recommend future research to clarify these connections. In consideration of institutional capacity, exposure to climate change and other stressors, as well as their potential economic impacts on TRBs, we also recommend further research on the Niger, Senegal, and Gambia River Basins. This study additionally suggests follow-up research on the following: Transboundary River Basin Management Institutions (TRBMIs); small TRBs, such as Tanoé and Cross; the Fouta Djallon Mountains of Guinea, where five of the 11 basins take their source; as well as the potential impacts of climate and other stressors on TRBs.

Finally, development organizations stand to make valuable contributions in the region by helping to build the capacity of TRBMIs to collaborate with one another to adaptively co-manage TRBs; to respond to the dynamic needs of local populations; to predict, monitor, and respond to climate variability and extreme events; and to address root causes of anthropogenic water stress.

1.0 INTRODUCTION

1.1 PURPOSE

The purpose of this desk study is to better understand the impacts of climate change on surface water resources in West Africa. To do so, it analyzes the vulnerability of the region's major TRBs to climate change in the past and assesses the potential effects of climate change in the future. It also provides an initial description — based solely on web resources — of the capacity of the region's five formal TRBMs to promote adaptation in their respective basins. This study is intended to inform targeted fieldwork focusing on both the institutions themselves and the larger basins in which they work, and contribute to the design of efforts to support TRBMs in West Africa in managing water resources in the face of climate change and other stressors, such as mounting population pressure and the expansion of hydropower and irrigation.

1.2 ANALYTICAL FRAMEWORKS

1.2.1 Assessing Climate Change Vulnerability

USAID employs the IPCC's (2007) definition of climate vulnerability in its assessment of the impacts of climate change on environments, people, and institutions. This definition states that vulnerability to climate is a function of exposure, sensitivity, and adaptive capacity, and it is widely lauded as the optimal available framework for assessing vulnerability (Kelly & Adger, 2000; Füssel & Klein, 2006; Kundzewicz, Mata, Arnell, Döll, Jimenez et al., 2008; Hahn, Riederer, & Foster, 2009).

Nevertheless, no model is flawless, and this particular model is no exception. One of its limitations is the assumption that its objects of analysis are passive. In other words, the model does not take into account the impacts that potentially vulnerable people, institutions, and ecosystems themselves have on the climate and environment. This model is unidirectional rather than cyclical, giving no consideration to the complex feedbacks between systems; thus, apart from its acknowledgement of the anthropogenesis of climate change — specifically the role of greenhouse gas emissions — it does not take into account the suite of biophysical, socioeconomic, and physical phenomena that influence and are influenced by climate.

This situation presents an opportunity for climate vulnerability assessments that take into consideration coupled human and natural systems (Liu, Dietz, Carpenter, Folke, Alberti et al., 2007). Such a framework recognizes the interdependence of political, socioeconomic, ecological, and biophysical systems as they influence climate, vulnerability, and the relations between them. In this study, we have attempted to employ such a framework, which we believe will help explain, among other things, the nonlinear relationship between climate and surface water availability in the region.

1.2.2 Institutional Adaptive Capacity

This study utilizes the Adaptive Capacity Wheel (ACW) (Gupta, Termeer, Klostermann, Meijerink, van den Brink et al., 2010) to assess transboundary river basin management institutions (TRBMs) in West Africa (see Chapter 5 of this study). This model is similar to adaptive management approaches (Pahl-

Wostl, 2007; Raadgever, Mostert, Kranz, Interwies, & Timmerman, 2008) in that it attempts to measure the ability of an institution to stimulate adaptive capacity within social and ecological systems. However, as compared to other approaches, the ACW appears to cover a wider spectrum than of factors contributing to adaptive capacity: fair governance, leadership, room for autonomous change, learning capacity, variety, resources, and their 22 criteria (see section 5.1). In addition to measuring the potential for promoting adaptive capacity, the ACW also illuminates the ways in which institutions can transform to maximize this potential. For these reasons, and in consideration of the literature available for river basin management institutions, the ACW was selected as the most appropriate model for this study.

Nonetheless, the ACW does not directly take into account the other two elements of climate change vulnerability, namely exposure or sensitivity. One approach that captures all three of these vulnerability factors is that of Bakker (2009), who gauges the institutional capacity of a TRBMI not only in terms of its capacity to adapt to climate change, but also in terms of its resilience to various other socioeconomic, biophysical, and geopolitical variables. Such an approach allows one to measure the differential impacts of climate change on different basins. For instance, the level of adaptive capacity of the Senegal River Basin and its management institution may not suffice given the harsh climate projections for this sub-region, whereas the same level of capacity in the Niger River Basin may go further in facilitating its adaptation to climate change. Such an approach may provide a valuable tool for the future research proposed in Annex A. This research, which would investigate in greater depth the adaptive capacity of TRBMIs in West Africa, would benefit from a more holistic approach capable of triangulating the broad range of socioeconomic, political, and environmental factors of vulnerability, resilience, and adaptation that can only be understood through *in situ* assessment.

2.0 BACKGROUND AND CONTEXT

2.1 PRESENTATION OF TRANSBOUNDARY RIVER BASINS IN WEST AFRICA AND THEIR MANAGEMENT INSTITUTIONS

In Africa, 60 watersheds cross at least one border and collectively cover around 40 percent of the continent (Niasse, Iza, Garane, & Varis, 2004). West Africa,¹ which occupies less than 25 percent of the continent, contains 47 percent of Africa’s watersheds and 11 TRBs; in turn, these basins cover 71 percent of the total surface of the region (United Nations Environment Programme [UNEP], 2008). Each of the region’s countries, with the exception of Cape Verde, shares at least one river with a minimum of at least one other country. On average, more than 40 percent of the water supply of any West African nation takes its source from outside that nation’s boundaries, and many of its nations have a water-dependency ratio² of 90 percent (Denton, Sokona, & Thomas, 2002). Together, these factors demonstrate the paramount importance of sound transboundary management of water resources in West Africa, especially in the face of climate change, which is expected to further stress scarce water resources. Table I lists the 11 TRBs in the region in descending order of river length.

TABLE I. TRBS IN WEST AFRICA, INCLUDING LENGTH, WATERSHED SIZE, AND RIPARIAN COUNTRIES

River Basin	River length (Km)	Watershed size (Km ²)	Riparian Country/Countries (source country in bold)
Niger	4,200	2,113,350	10: Algeria, Benin, Burkina Faso, Cameroon, Chad, Guinea , Mali, Niger, Nigeria, and Sierra Leone
Senegal	1,800	289,000	Four: Guinea , Mali, Mauritania, and Senegal
Volta	1,610	441,000	Six: Burkina Faso , Benin, Côte d’Ivoire, Ghana, Mali, and Togo
Lake Chad	1,400	2,388,700	Nine: Algeria, Chad , Cameroon, Central African Republic, Libya, Niger, Nigeria, and Sudan
Komoé River	1,160	78,000	Four: Burkina Faso , Côte d’Ivoire, Ghana, and Mali
Gambia	1,130	77,000	Four: The Gambia, Guinea , Guinea Bissau, and Senegal
Sassandra	720	75,000	Two: Côte d’Ivoire and Guinea

¹ Unless otherwise noted, West Africa is defined in this study as the 15 nations of the Economic Community of West African States (ECOWAS) – Benin, Burkina Faso, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Côte d’Ivoire, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo – in addition to Cameroon, Chad, and Mauritania, totaling 18 in all.

² The water-dependency ratio (otherwise known as the downstream dependency ratio) refers to the percentage of freshwater resources originating outside a country.

River Basin	River length (Km)	Watershed size (Km ²)	Riparian Country/Countries (source country in bold)
Corubal	565	23,840	Two: Guinea and Guinea-Bissau
Ouémé (Weme)	510	50,000	Three: Benin , Nigeria, and Togo
Tanoé	400	16,000	Two: Côte d'Ivoire and Ghana
Cross	200	60,000	Two: Cameroon and Nigeria

Sources: Oki and Sud (1998); Ardoin-Bardin, Servat, and Université des sciences et techniques de Montpellier (2004); UNEP (2008a); Offem, Akegbejo-Samsons, and Omoniyi (2010)

Five major institutions in West Africa manage TRBs: the Senegal River Development Organization (Organisation pour la mise en valeur du fleuve Sénégal, OMVS), the Gambia River Basin Development (OMVG), the Volta Basin Authority (VBA), the Niger Basin Authority (NBA), and the Lake Chad Basin Commission (LCBC). It is assumed that the other major transboundary river basins lack formal management institutions because of their minimal prioritization by their riparian countries, perhaps due to the relatively small size and economic contribution of these rivers. For the case of Komoé, which is greater in length and watershed size than the Gambia, it is presumed that the nature of its location primarily within Côte d'Ivoire means that the other riparian countries (Burkina Faso, Ghana, and Mali) may not be interested in pursuing its co-management. Table 2 lists these five institutions, locations, member states, and dates of establishment in descending order of length of the rivers they manage.

TABLE 2. MAJOR RIVER BASIN MANAGEMENT INSTITUTIONS IN WEST AFRICA

River Basin	Management Institution	Location of Institution	Member States	Date of Establishment
Niger	Niger Basin Authority (NBA)	Niamey, Niger	Benin, Burkina Faso, Cameroon, Guinea, Côte d'Ivoire, Mali, Niger, Nigeria, Chad	1963
Senegal	Senegal River Basin Development Organization (OMVS)	Dakar	Guinea, Mali, Mauritania, Senegal	1972
Volta	Volta Basin Authority (VBA)	Ouagadougou, Burkina Faso	Burkina Faso, Benin, Côte d'Ivoire, Ghana, Mali, Togo	1961
Lake Chad	Lake Chad Basin Commission (LCBC)	N'djamena, Chad	Algeria, Cameroon, Niger, Nigeria, Central Africa Republic, Chad, Sudan	1964
Gambia	Gambia River Basin Development Organization (OMVG)	Dakar, Senegal	The Gambia, Guinea, Guinea Bissau, Senegal	1967

Source: Adapted from OECD, 2006

2.1.1 Niger River Basin

The Niger River Basin is the longest river in West Africa. It covers about 7.5 percent of the continent and spreads over 10 countries (see Figure 1 and Table 3). The basin takes its source from the Fouta Djallon Massif in southeastern Guinea and runs in a crescent through several countries – Mali, Niger, Benin, and Nigeria, discharging through the massive Niger Delta into the Gulf of Guinea in the Atlantic Ocean. There are no uniform climate and rain patterns in the basin; rather, it traverses almost every possible ecological and climatic zone in West and Central Africa (Andersen & Golitzen, 2005). Table 3 lists some of its defining features.

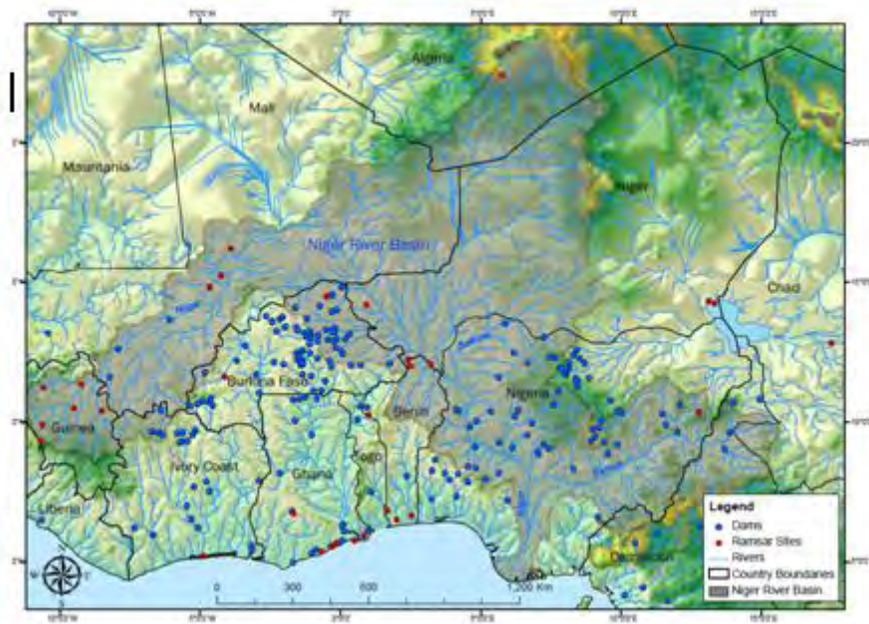
TABLE 3. NIGER RIVER BASIN

Basin	Area (Km ²)	Population	Major Dams	Water Uses	Spatial Distribution	
					Country	Percent Basin
Niger River Basin	2,270,000	106 million	Dadin Kowa Selingue Kanji Goronyo Jebba Shiroro	Agriculture Domestic Hydropower	Nigeria	25.7
					Mali	25.5
					Niger	24.8
					Algeria	8.5
					Guinea	4.3
					Cameroon	3.9
					Burkina Faso	3.4
					Benin	2.0
					Cote D'Ivoire	1.0
					Chad	0.9

Source: UNEP, 2008b; and FAO, 2007

The Niger Basin Authority (NBA), known in French as the Autorité du Bassin du Niger, was launched in 1980 in Niamey to coordinate the interstate development of the river's natural resources by synchronizing the national resource development policies of its member states. In 1986, the mandate of the NBA was extended to promote sustainable and cooperative development of the Niger River Basin. Its member countries include Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Guinea, Mali, Niger, and Nigeria. In 2002, the NBA initiated a new strategy known as the Shared Vision, which calls for improved harmonization between its member states on efforts related to natural resource management, agriculture, fisheries, water use, transport, industry, and information sharing.

FIGURE 1. NIGER RIVER BASIN AND ITS RIPARIAN COUNTRIES



Source: UNEP, 2008

2.1.2 Senegal River Basin

The Senegal River basin experienced a severe drought in the 1960s and 1970s, during which hundreds of thousands of people near the river faced frequent food crises and famine. In March 1972, three of the riparian countries — Mali, Mauritania, and Senegal — established the OMVS to oversee the coordinated exploitation of the basin's resources.

The Senegal River is the second longest river in West Africa (Figure 1). It covers around 1.6 percent of the region and spreads across four countries: Guinea, Mali, Mauritania, and Senegal. Its source is in Guinea; it runs through western Mali and then flows west, forming the border between Mauritania and Senegal. The basin covers around 289,000 km² and is about 1,800 km long. The river has three principal tributaries — the Bafing, Bakoye, and Faleme — all of which originate in the Fouta Djallon Mountains in Guinea and together produce over 80 percent of its flow. The Bafing alone contributes about half of the Senegal River's flow at Bakel. Most of the Senegal River basin is located in Sub-Saharan desert climates. The basin has three distinct parts – the upper basin, which is mountainous; the valley; and the delta, which is a source of biological diversity and wetlands.

To counter the impacts of the late twentieth-century Sahelian droughts, two dams, Dama and Manantali, were constructed in 1986 and 1988. Hundreds of canals were also built across the river in order to (i) increase the sustainability of basin inhabitants; (ii) decrease the vulnerability of Senegal River basin countries to climate variability; and (iii) accelerate economic and inter-state cooperation. A hydropower plant was later added to the Manantali dam in 2001.

FIGURE 2. SENEGAL RIVER BASIN AND ITS RIPARIAN COUNTRIES



Source: UNEP, 2008b

Diama dam, in the Senegal River delta, is approximately 23 km from the mouth of the river. Its main purpose is to raise the water level upstream in order to facilitate irrigation; to fill Guiers Lake in Senegal and Rkiz Lake in Mauritania; and to block seawater intrusion. Manantali dam is approximately 1,200 km from the river's mouth, and its purpose is to attenuate extreme floods, generate electric power, and store water in the wet season to augment dry-season flows for the benefit of irrigation and navigation (World Bank, 2009). The dams are operated by the Société de Gestion et d'Exploitation de Diama (SOGED, or the Diama Dam Management Company), and the Société de Gestion de l'Energie de Manantali (SOGEM, or the Manantali Energy Management Company).

The Senegal River Basin's population is estimated to be around 3,500,000 (African Network of Basin Organizations [ANBO], 2007). More than 85 percent of the basin's population lives near the river (see Table 4). The rate of population growth in the Senegal River Basin is about 3 percent per year, which is quite high compared to the average rate of population growth in the four countries (between 2.5 percent and 2.7 percent per year). Different ethnic groups, including Peul, Toucouleur, Soninke, Malinke, Bambara, Wolof, and Moor, characterize the river's population.

TABLE 4. THE SENEGAL RIVER BASIN

Basin	Area (Km ²)	Population (millions)	Major Dams	Water Use	Spatial distribution	
					Country	% of basin
Senegal River Basin	289,000	3.5	Diama and Manantali	Agriculture Domestic Industry Hydropower	Mali	53
					Mauritania	26
					Guinea	11
					Senegal	10

Sources: Food and Agriculture Organization (FAO), 2007; UNEP, 2008b

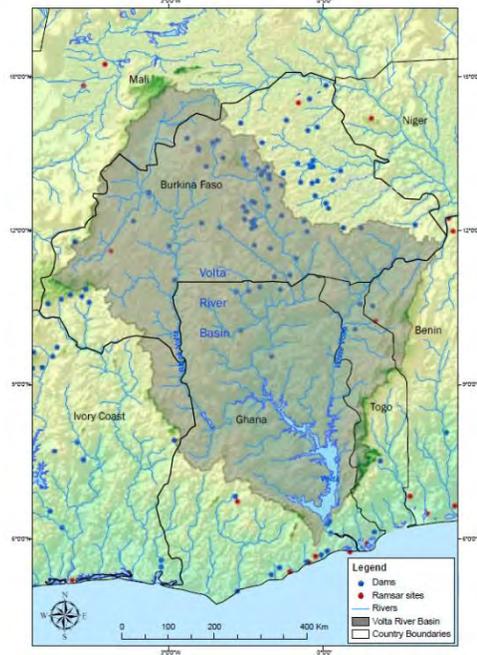
2.1.3 Volta River Basin

The Volta River basin covers an area of 400,000 km² in six West African nations, including Burkina Faso, Ghana, Togo, Benin, Cote d'Ivoire, and Mali. The river itself is more than 8,242.8 km long. Rainfall in the basin ranges from 1,600 mm in Ghana to 260 mm in Burkina Faso; both rainfall and runoff have been declining in some parts of the basin since the 1970s (GEF-Volta, 2013). This decline has led to a shift in some areas from a bimodal to a mononodal precipitation scheme (Opoku-Ankomah, 2000). The main attributes of the Volta include the Black Volta (147,000 km²), White Volta (106,000 km²), Oti (72,000 km²), and Lower Volta (73,000 km²). Collectively, they drain around 40,400 million cubic meters (Mm³) per year (McCartney, Forkuor, Sood, Amisigo, Hattermann, et al., 2012).

TABLE 5. VOLTA RIVER BASIN

Basin	Area (Km ²)	Population (millions)	Major Dams	Water Use	Spatial distribution	
					Country	% of basin
Volta River Basin	400,000	18.64	Akosombo Kpong, Komienga, and Nangodi	Agriculture Domestic Hydropower Industrial Mining Tourism	Burkina Faso	43
					Ghana	42
					Togo	6.40
					Benin	4.10
					Mali	3.69
					Cote d'Ivoire	2.99

FIGURE 3. VOLTA RIVER BASIN AND ITS RIPARIAN COUNTRIES



Source: UNEP, 2008b

On April 16, 1961, the riparian countries of the Volta River Basin came together to establish the Volta River Authority to (i) generate electrical power; (ii) built and operate dams along the river; and (iii) develop lakes for fish and transportation and lakeside areas for health and well-being.

2.1.4 Lake Chad Basin

Lake Chad Basin is the largest inland drainage area in Africa and covers an area of 2,434,000 km², equal to 8 percent of the total area of the African continent. The basin extends through seven countries: Algeria, Cameroon, Niger, Nigeria, Central Africa Republic, Chad, and Sudan. Its climatic regime is dominated by four major zones: (i) the Saharan climate zone, which receives less than 100 mm of rainfall annually; (ii) the Sahelian-Saharan zone, which receives an average of 100 mm to 400 mm per year; (iii) the Sahelian-Sudanese zone, within which rainfall annually varies between 400 mm and 600 mm; and (iv) the Sudanese-Guinean zone, averaging 600 mm to 1,500 mm annually (Lake Chad Basin Commission [LCBC], 2013).

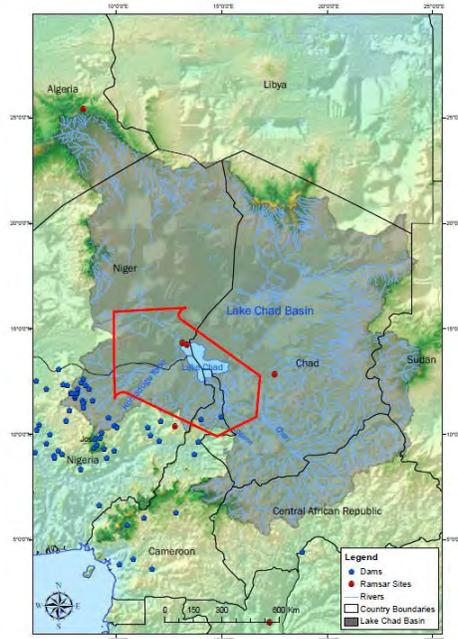
TABLE 6. LAKE CHAD BASIN

Basin	Area (Km ²)	Population (millions)	Major Dams	Water Use	Spatial distribution	
					Country	% of basin
Lake Chad	2,434,000	37 million	Mbakaou – 2.6 Mm ³	Agriculture Domestic Hydropower Mining Tourism	Chad	43.9
					Niger	29
					Central Africa	9.2
					Nigeria	7.5
					Algeria	3.9
					Sudan	4.2
					Cameron	2.1

Source: FAO, 2007; UNEP, 2008b

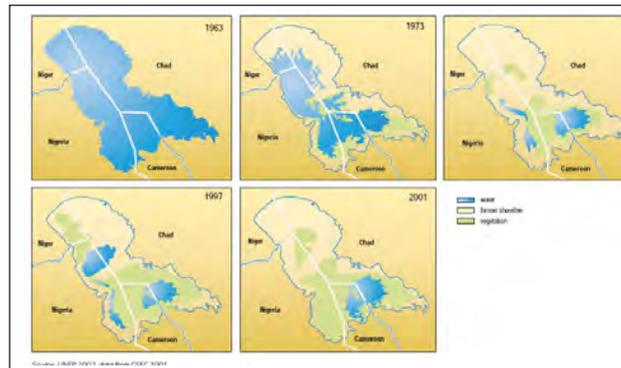
Cameroon, Niger, Nigeria, and Chad established the Lake Chad Basin Commission in 1964 with the objective of i) sustainably and equitably managing the lake’s natural resources; ii) preserving the lake’s ecosystems; and iii) promoting economic integration and peace between the founding countries. In 1996, the Central African Republic became a member of the Lake Chad Basin Commission, followed by Libya in 2008. It should be noted that the Lake Chad Basin Commission manages only about 20 percent, or 427,500 km², of the total area of the basin.

FIGURE 4. LAKE CHAD BASIN AND ITS RIPARIAN COUNTRIES



Source: UNEP, 2008b

FIGURE 5. CHANGE IN SURFACE AREA OF LAKE CHAD BETWEEN 1963 AND 2001



Source: LCBC, 2013

2.1.5 The Gambia River Basin

The Gambia River basin is also located in West Africa (Figure 6), covers an area of 77,054 km², and runs for approximately 1,130 km. Guinea, Senegal, The Gambia, and Guinea Bissau share it. From its origin in the mountainous regions of the Fouta-Djallon in the Guinean highlands to its estuary on the Atlantic Ocean, the Gambia River Basin runs over a distance of 1,180 km. It flows 205 km in Guinea, 485 km in Senegal, and 490 km in The Gambia (UNEP, 2008a).

The majority of the Gambia River Basin is located in the Sudano-Sahelian (dry tropical) ecological zone in Senegal and Gambia, and in the Sudanian (wet tropical) zone in Guinea. The annual rainfall ranges from 1,200 mm to 4,500 mm in Guinea; 1,200 mm in the North to 2,400 mm in the South of Guinea Bissau; and between 500 mm and 1,000 mm in Senegal and The Gambia. It should be noted that 90 percent of the river's annual discharge occurs between July and October (UNEP, 2008a).

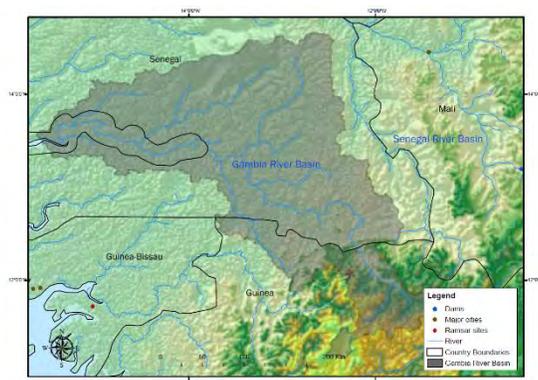
OMVG manages the Gambia River Basin. This organization was established in 1978, and The Gambia, Guinea, Guinea-Bissau, and Senegal administer it. The main goal of OMVG is to promote economic development along the Gambia River Basin by (i) achieving self-sufficiency in food for country members; (ii) improving rural incomes and ensuring a more equitable distribution of income among country members; and (iii) promoting industrial development. Table 7 lists the main characteristics of the basin.

TABLE 7. THE GAMBIA RIVER BASIN

Basin	Area (Km ²)	Population (millions)	Major Dams	Water Use	Spatial distribution	
					Country	% of basin
The Gambia River Basin	77,054	19.9	Balingho and Kekreti	Agriculture Domestic Mining (traditional)	Senegal	70.9
					Guinea	15.4
					Gambia	13.7
					Guinea Bissau	0.021

Source: UNEP, 2008b

FIGURE 6. THE GAMBIA RIVER BASIN AND ITS RIPARIAN COUNTRIES



Source: UNEP, 2008b

2.2 DAMS

The following table illustrates the major dams of the five largest transboundary basins in West Africa. Unfortunately, no qualitative information could be found about the roles their managing units play in administering water resources or facilitating livelihood activities in the basin.

TABLE 8. DAMS OF MAJOR WEST AFRICAN RIVER BASINS

River Basin	Name of Dam	Year of Creation	Managing Unit	Uses
Niger	Dadin Kowa	1984	Upper Benue River Basin Development Authority	Irrigation Hydropower
	Selingue	1982	L'Office de Développement Rural de Sélingué (ODRS)	Irrigation
Senegal	Diama	1986	Société de Gestion et d'Exploitation de Diama (SOGED, or the Diama Dam Management Company)	Prevent saltwater intrusion into the lower valley
	Manantali	1987	Société de Gestion de l'Energie de Manantali (SOGEM, or the Manantali Energy Management Company)	Irrigation Hydropower Navigation

River Basin	Name of Dam	Year of Creation	Managing Unit	Uses
Volta	Akosombo	1965	Volta Basin Authority	Commercial fishing and navigation Electricity Irrigation
	Nangodi	1958	Unknown	Unknown
	Kompienga	1988	Burkina Faso	Irrigation, fishing, hydroelectric power
Lake Chad	Mbakaou	1971	The Lake Chad Basin Commission	Agriculture Domestic Industry Mining Hydropower
The Gambia	No dams to date; two currently under construction.			

Source: UNEP, 2008b

2.3 RELIANCE ON RIVER BASINS

In 1995, the per capita water availability, including both surface and groundwater, for West Africa's 227 million people was approximately 12,618 m³. Only a decade later, this availability had dwindled to 9,355 m³ due not only to variability in temperature and precipitation, but more importantly to a rapid population growth rate of more than 3 percent. By 2015 and 2025, these water availability levels are expected to further diminish to 7,110 and 5,545 m³ respectively, taking into consideration population increases, natural climate variability, and greenhouse gas-induced climate change (GWP and WATAC, 2000; UNEP and WRC, 2008).³

According to UNEP's definition of water vulnerability, stress, and scarcity, this finding places Benin, Côte d'Ivoire, Niger, Senegal, and Mauritania under conditions of water vulnerability⁴ — and Burkina Faso, Ghana, Nigeria, and Togo under water stress⁵ — by the year 2025. It goes without saying, however, that great disparities in water availability and access exist within each of the countries of West Africa, irrespective of their general classification of water pressure, especially in the more arid areas of the region such as the northern Sahel. Furthermore, this definition does not take into account livelihood adaptations, especially in arid regions, that may render some populations less vulnerable to reductions in water availability.

As listed in the tables above, more than 185 million people inhabit the five 'managed' river basins in West Africa, with even more relying on river water, albeit indirectly through channeled potable water services, electricity from hydropower, and food produced with basin water. Current total freshwater withdrawal in West Africa is 11 km³ per year (GRID-Arendal, 2002) for agriculture, industry, and

³ See also UNEP (2008b).

⁴ Per capita annual availability of 1,700 to 2,500 m³.

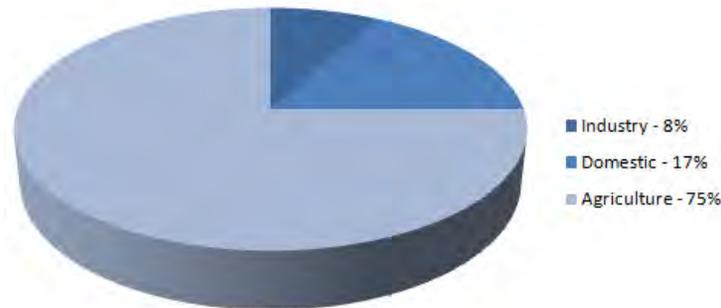
⁵ Per capita annual availability of 1,000 to 1,700 m³.

domestic uses combined. Of this total, approximately 8 percent is used for industry, 17 percent for domestic purposes, and 75 percent for agriculture, including both farming and livestock production (see Figure 7). Total withdrawal is expected to increase to approximately 36 km³ per year by 2025 (GRID-Arendal, 2002).

2.3.1 Water Stressors

Such increases in demand are due to a number of exacerbating factors. UNEP identifies specific non-climate stressors on water sources in Africa (UNEP, n.d.). Among them are increasing populations and economic growth, inadequate water management and infrastructure, and inefficient water provision. Also noted is the inadequacy of joint governing bodies in sustainably managing transboundary resources – as well as a general decline in non-renewable aquifers, which is presumed to further increase demand for river water. Additionally, certain environmental processes such as land degradation, soil erosion, and deforestation can decrease freshwater supply by increasing runoff and weakening local precipitation mechanisms (Descroix et al., 2009). On the side of access, price distortion continues to plague many communities in which the poor pay more than the wealthy for water.

FIGURE 7. WATER USE IN WEST AFRICA



Source: GRID-Arendal, 2002

2.4 FUNDED PROJECTS

The following table lists major ongoing project being implemented with TRBMIs in West Africa. It is important to note that only those projects found via an internet search are presented; a deeper investigation would be required to produce a full list.

TABLE 9. CURRENT MAJOR FUNDED PROJECTS OF WEST AFRICAN TRBMIS⁶

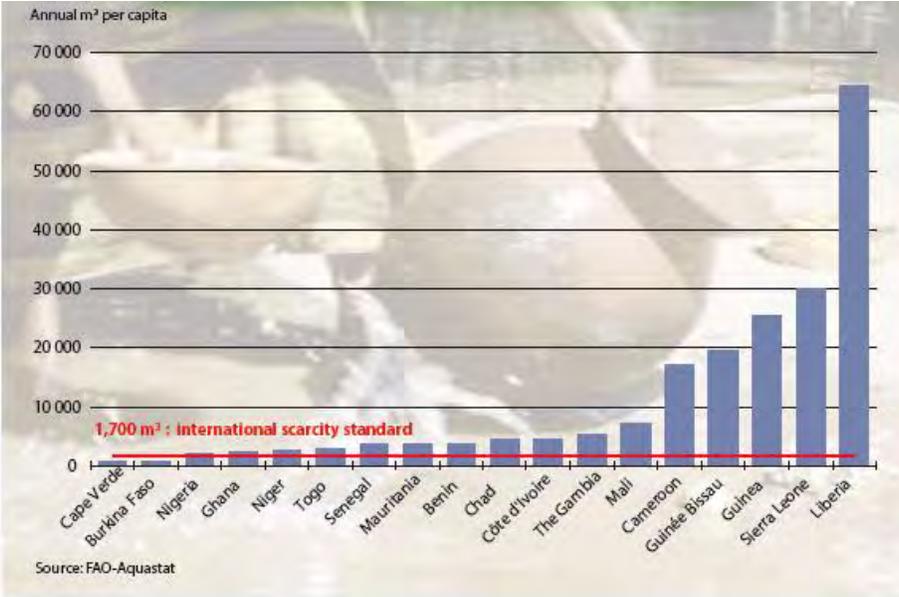
Institution	Project		
	Project name	Donor	Objectives
Senegal River Development Organization	Integrated Management of Water Resources	The World bank The Global Environment Facility	Create and rehabilitate village irrigation parameters. Construct landing infrastructure and conserve fisheries.
The Gambia River Basin Development Organization	Construction of Sambangalou Dam and Kaleta Dams	The African Development Bank	Reinforce cooperation between riparian countries. Facilitate regional integration of the energy sector.
Volta Basin Authority	Water and Nature Initiative Project	International Union for Conservation of Nature	Improve water governance in the basin.
	The Challenge Program on Water and Food (CPWF)	Consultative Group on International Agricultural Research	Increase the resilience of social and ecological systems through better water management for food production.
Niger Basin Authority	Programme de Renforcement des Capacités	Canadian International Development Agency	Reinforce the institutional and organizational capacity of the Niger Basin Authority.
Lake Chad Basin Commission	Sustainable Water Resources Management in Lake Chad Basin	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)	Support the Commission to develop its planning, cooperation, and communications capacities.

3.0 CLIMATE IMPACTS ON TRANSBOUNDARY RIVER BASINS

3.1 CLIMATE AND FRESHWATER RESOURCES

By 2025, West Africa is expected to confront economic water scarcity (World Wide Fund for Nature [WWF], 2003).⁷ Figure 8 below shows the availability of freshwater resources for West African countries in comparison to the international water scarcity standard of 1,700 m³ per capita, per year (Organisation for Economic Co-operation and Development [OECD], 2006).

FIGURE 8. PER CAPITA WATER RESOURCE AVAILABILITY IN WEST AFRICA



Source: OECD, 2006

This chapter examines the historical and foreseen impacts of climate variability and change on river basins, ecosystems, and water supply and quality in West Africa. This region, and the Sahel in particular, is one of the most climatically variable in the world, and this variability increases as one travels northward from its sub-humid zone in the South to the semi-arid zone in the North (Centre for

⁷ The WWF (2003) defines water scarcity as such: by 2025, primary water supply is expected to increase by 25 percent above its current level; however, this supply will still be lower than 60 percent of total potentially exploitable freshwater resources in a given area.

International Forestry Research [CIFOR], 2005). Both historical variability and projected climate change for the region are expected to further reduce future river basin water supply. In fact, water simulations suggest reductions in West African river flows by 15 to 20 percent for 2020 and by 20 to 40 percent for 2050 (CIFOR, 2005).

Despite its counterintuitive nature, the relationship between mounting climate change and dwindling freshwater supplies in West Africa is actually quite dynamic. This is due not only to geographic disparities in precipitation and temperature, but also to a host of other factors that interact with climate and hydrology to determine surface water supply, namely land use/land cover change and extreme events like drought, flooding, and fires. This chapter will focus exclusively on the biophysical effects of these factors as they influence climate and hydrology, while Chapter 4 will address their socioeconomic dimensions. The text box below defines key terms related to river basin hydrology⁸ and is followed by Figure 9, which depicts the interaction of these processes.

DEFINITIONS

Basin

A river basin comprises the land area drained by a river and its tributaries.

Watershed

A watershed, or catchment, is a topographic area that is drained by a river or stream; it is made up of the land area that divides waters flowing to different rivers, basins, or seas.

Evapotranspiration

Evapotranspiration is the sum of evaporation and plant transpiration from land surface to the atmosphere.

Surface runoff

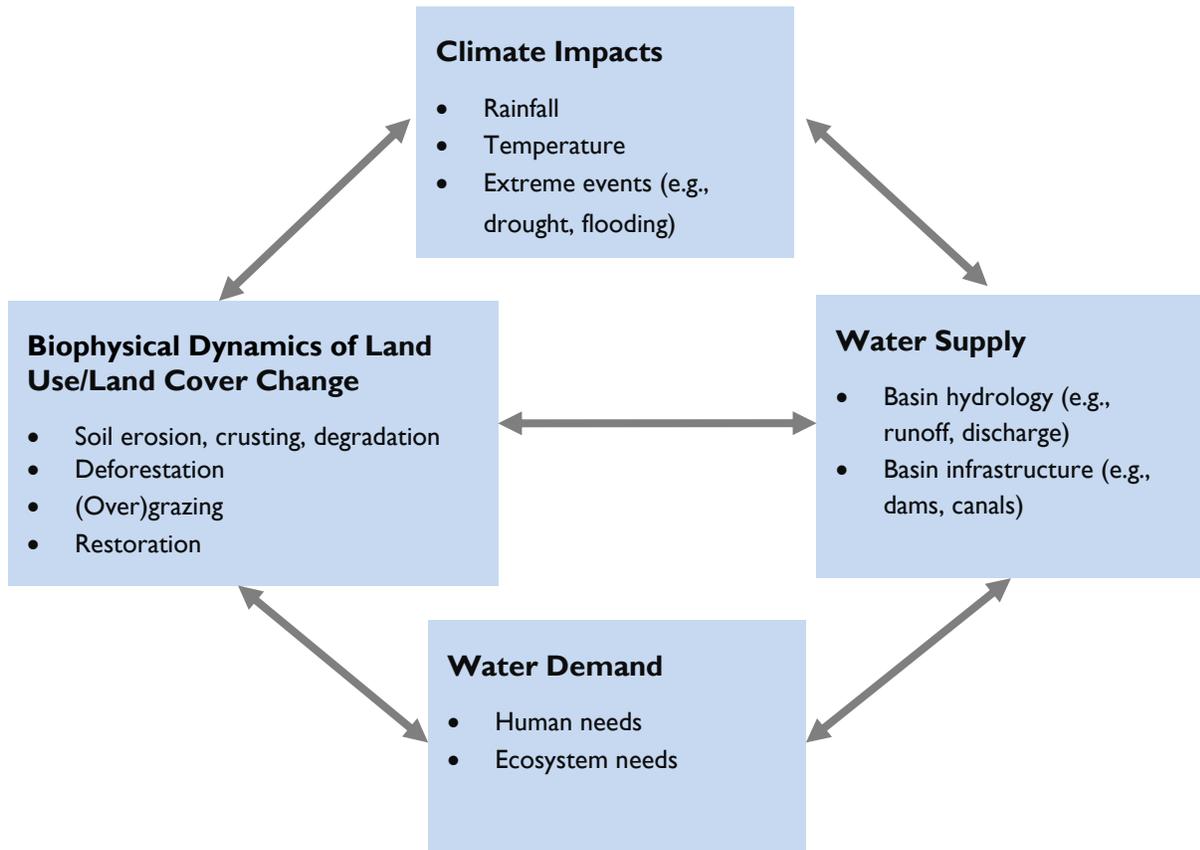
Surface runoff occurs when water from rain or other sources flows over soil that is infiltrated to full capacity. Runoff that is not extracted from the land surface by evaporation and transpiration is delivered to streams, lakes, and oceans. In this study, surface runoff is measured as a coefficient of rainfall.

Discharge

Discharge is the volume of water that passes through a given cross section of a river or stream in a single unit of time; it is usually measured in cubic feet per second (cfs) or cubic meters per second (cms). It is also referred to as flow.

⁸ All definitions were adapted from the Google dictionary.

FIGURE 9. INTERACTIONS BETWEEN CLIMATE, BIOPHYSICAL LAND DYNAMICS, AND RIVER BASIN WATER AVAILABILITY



The above diagram explains the interactions between climate, biophysical land dynamics, and river basin water availability. The arrows represent feedbacks between different variables. For example, changes in climate (precipitation and temperature) directly influence river basin hydrology, which is also shaped by water demand and the biophysical dynamics of land use/land cover change. Among other things, this diagram helps explain the inconsistent relationship between rainfall and river basin hydrology in the region – that increased rainfall does not necessarily correlate with increases in river basin water supply, independent of water demand (withdrawals), because of the confounding roles of temperature, basin infrastructure, and — perhaps most importantly — the biophysical dynamics of land use/land cover change, which play a key role in determining runoff and discharge rates. An example of the latter is the role of deforestation, which reduces the water-holding capacity of watersheds, thus increasing runoff all else being equal (Descroix, Mahé, Lebel, Favreau, Galle, et al., 2009).

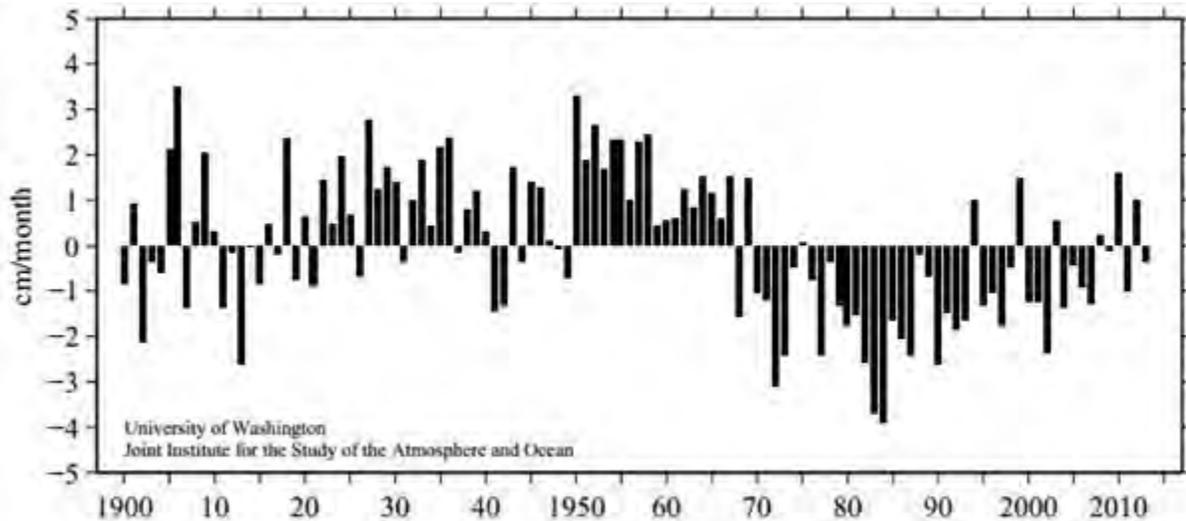
Note on climate projections used in this report: Although produced the same year, the 2013 IPCC Fifth Assessment Report was not available at the time this study was drafted. The reference levels of the 2007 IPCC report were used throughout this report. However, it is unlikely that use of the new projections would change the conclusions of this report, as the projections for Africa did not change dramatically, nor was there an increased confidence in the results.

3.2 PRECIPITATION AND SURFACE WATER SUPPLY

3.2.1 Historical precipitation

Any study on the climate of West Africa would be remiss not to mention the droughts of the late century, which wrought widespread devastation on local populations and ecosystems. In fact, it is still questioned whether the region has yet recovered from this period of desiccation. Declines in rainfall over the past half century in West Africa, particularly in the Sahel, have been associated mainly with a reduction in the number of significant rainfall events during the rainy season of July through September. For West Africa as a whole during the 1968-1991 period, rainfall declined 20 to 40 percent as compared to rainfall during the 1931-1960 period (Chappell and Agnew, 2004; Dai, Lamb, Trenberth, Hulme, Jones, et al., 2004; Nicholson, 2005). This variability in rainfall has been associated with fluctuations in atmospheric circulation and tropical sea-surface temperature (SST) patterns in the Atlantic, Indian, and Pacific Oceans (Dai et al., 2004). While rainfall variability has continued, since 1991, annual rainfall in the Sahel has recovered somewhat. Figure 10 depicts the rainfall anomalies in the Sahel for much of the twentieth century.

FIGURE 10. SAHEL RAINFALL ANOMALIES 1900 TO 2013



Source: Accessed from: <http://jisao.washington.edu/data/sahel/> (8/14)

3.2.2 Historical Precipitation and Its Relation to Surface Water Supply

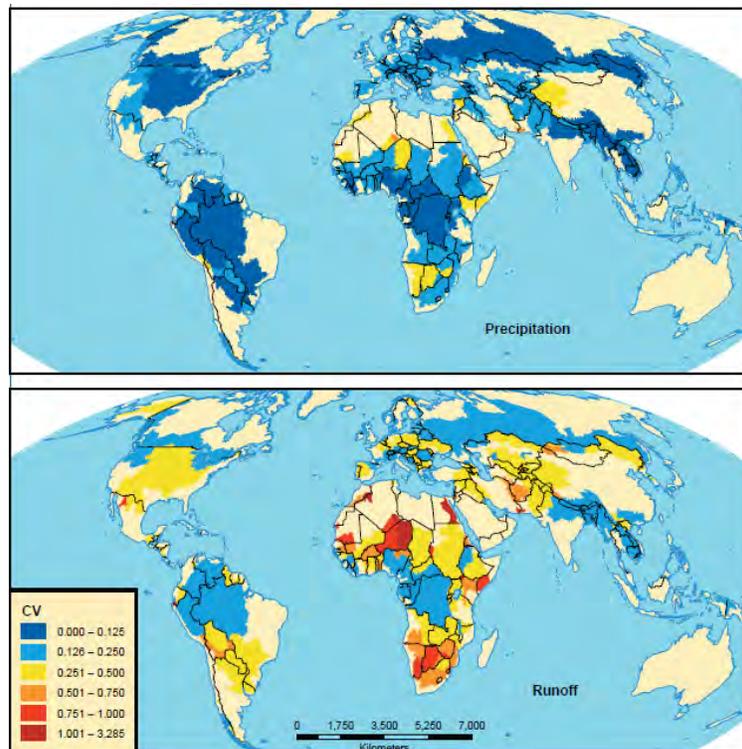
Studies related to historical precipitation and water supply use various hydrologic variables, such as runoff and discharge, as indicators of surface water supply. Of these indicators, runoff is the most common. Since the great droughts of the past century in the Sahel, through which six of the 11 TRBs run, several studies have shown that runoff has been decreasing by up to 60 percent alongside decreases in rainfall (Milly, Dunne, & Vecchia, 2005; Mahe & Olivry, 1999; Ardoin et al., 2009; Roudier & Mahe, 2010a). The area of the region in which the relation between rainfall and runoff has demonstrated a certain degree of spatial linearity on the basin scale is in the Niger and Lake Chad basins, where runoff is highly sensitive to rainfall variation. There, annual river discharge largely varies in conjunction with rainfall variability. However, this relation proves quite different at the temporal scale, as relative

hydrologic variability (rainfall, evapotranspiration, runoff, and river discharge) is much higher in the dry period than in the wet period (Li et al., 2004), indicating a higher level of climate vulnerability in the dry season in these basins.

These studies may seem to suggest a consistently direct correlation between decreasing rainfall and declining runoff; however, this relationship is actually quite variable at different spatial and temporal scales (Conway et al., 2008), resulting in economic, environmental, and social burdens in many locations (Sutcliffe & Knott, 1987; Grove, 1996; Laraque et al. 2001; Conway, 2002; Ogotunde et al., 2006; Hamandawana 2007). In 2010, De Stefano, Duncan, Dinar, Stahl, and Strzepek, et al. conducted a study of baseline and future global changes in water availability. Using both climate and hydrologic models, they calculated the coefficient of variation (CV) for precipitation and runoff as a proxy for surface water supply for a baseline historical period of 1961-1990; they also calculated the CV geographically by country-basin unit (Oyebande & Odunuga, 2010). They then projected precipitation and runoff for 2030 and 2050 using 2007 IPCC climate projections to generate dry, medium, and wet scenarios for these variables. Figure 11 below shows this global distribution of precipitation and runoff for the baseline period.

As with studies of Sahelian desiccation for the same time period, the map shows relatively high CVs for precipitation for parts of West Africa, and even more so for runoff. Their study argues that no steady correlation between precipitation and runoff exists for this time period on the global level nor for West Africa due to different land surface conditions in different sites. These findings buttress the argument in this study that runoff, and surface water supply more generally, is not simply a function of climate. Rather, land use/land cover change also account for spatial and temporal differences in the relationship between precipitation and runoff (as a proxy for surface water supply).

FIGURE 11. CV OF ANNUAL PRECIPITATION AND RUNOFF FOR COUNTRY-BASIN UNITS, 1961-1990



Source: De Stefano et al., 2010

Dezetter, Girard, Paturel, Mahe, Ardoin-Bardin et al. (2008) present another example of the spatial inconsistency in rainfall-runoff relations in West African transboundary basins. They explain that below-average rainfall after 1970 correlated with a notable decrease (~30 percent) in runoff for 36 of 49 catchment areas on the Niger, Volta, Comoé, and Bandama rivers located in Burkina Faso, Côte d'Ivoire, Guinea, Mali, and Niger. However, these same negative rainfall anomalies were experienced alongside increased runoff in certain right-bank⁹ tributaries of the Niger and the Nakambé at Wayen. Additionally, their study shows that for the 36 catchments for which runoff decreased, annual discharge also decreased — in many cases by more than half — between 1970-1995 and 1950-1995.

In attempting to explain the causes of this inconsistency in the relationship between rainfall and runoff, Descroix and Amogu (2009) define what they refer to as the “Sahelian” paradox — that a decrease in rainfall can precede an increase in the calculated runoff coefficient and rate of discharge. During the second half of the twentieth century, this idea held true for a number of Sahelian tributaries of the Niger River, namely the Sirba, Gorouol, and Dargol (Amani and Nguetora, 2002), and to a greater extent, the Nakambé River, a tributary of the Upper Volta (Mahé et al., 2005). Conversely, in the Sudanian¹⁰ region, a more intuitive decrease in discharge accompanied rainfall shortages along the Ouémé River and certain tributaries of the Niger River (Alibori, Sota, Irané, and, to a lesser extent, the Mékrou, Tapoa, Goroubi, and Diamangou) (Descroix & Amogu, 2009). It should be noted that Sahelian regions generally receive less than 700 mm of rainfall per year, while Sudanian zones receive between 700 mm and 1300 mm per year.

What these studies describe is a decline in discharge for West Africa's rivers during the past century. In the largest rivers in the region, the Senegal and the Niger, Mean Annual Discharge (MAD) decreased in proportions almost twice as large as decreases in rainfall between 1970 and 2000 (Lebel, Diedhiou, & Laurent, 2003). However, as noted above, some basins show an inverse correlation between rainfall and discharge. In general, the former is true for Sudanian basins and the latter for Sahelian. The reason for these spatial inconsistencies is relevant to this study and to the fundamental challenge of isolating climate from other factors influencing surface water supply. Descroix et al. (2009) stress that the answer to this query lies in analyzing the impacts of land cover change on the region's hydrology. Specifically, they clarify how vegetation, and to a lesser extent, fallow land, increases a watershed's water holding capacity. Conversely, deforestation, soil crusting, and soil compaction increase runoff, which holds true for different types of climates and especially for arid and semi-arid regions. This issue points to a need for future research to understand the tradeoffs between land use/land cover change, runoff, river basin discharge, and groundwater recharge levels.

Moreover, in regards to land cover change and discharge, it should be noted that almost half of the Niger Basin is endorheic, referring to smaller closed catchments that do not drain into the larger basin. In these areas, the water table rose during the latter half of the twentieth century despite the dramatic decreases in rainfall (Descroix et al., 2009). This phenomenon, known as the Niamey paradox, is similar to the Sahelian paradox mentioned above in that it attributes spatially and temporally variable land use/land cover changes to fluctuations in runoff, discharge, and groundwater recharge. In the case of the Niger Basin, decreases in rainfall actually occurred alongside increases in runoff due to soil erosion and crusting, resulting in large part from human activities. However, since this trend occurred in an endorheic catchment, the runoff did not drain into the river and was instead absorbed by the aquifer (Lebel, Cappelaere, Gallea, Hananc, & Kergoat, et al., 2009). Conversely, along the same latitudes in the

⁹ From the perspective of looking downstream.

¹⁰ Sudanian refers to the ecological zone south of the Sahel. See, for example, <http://worldwildlife.org/ecoregions/at0722>.

Lake Chad basin, which is completely endorheic, groundwater levels fell during the same period (Descroix et al., 2009), again pointing to site-specific land use/land cover change as complicating the links between rainfall and surface water supply.

Additionally, the percentage of West Africa under cultivation has escalated from 10 percent in the 1950s to 80 percent nowadays, spawning massive runoff-inducing land cover changes. Other leading factors of vegetation loss affecting runoff and discharge include demographic pressure, which likely explains some of the increase in agriculture, an increase in deforestation for fuel use, and land degradation and vegetation mortality due to drought (Cappelaere et al., 2009). **Climate, therefore, is not the single or even most important factor in determining water supply.** Both natural and anthropogenic land cover change must be taken into account on a site-by-site basis, as has been demonstrated also in the work on the recent “greening” of the Sahel (Herrmann et al., 2005; Hutchinson et al., 2005; Olsson et al., 2005).

As the above studies demonstrate (see summary in Table below), the significance of spatial scale in the rainfall-runoff-discharge relationship cannot be understated. As Descroix et al. (2009) signal, the most important factor at the local scale is changing land cover, which influences soil hydrodynamic processes. However, at larger scales, a more dominant factor in river discharge is groundwater discharge flow, which can eclipse or even reverse the local impacts of land cover change.

TABLE 10. ILLUSTRATIVE EXAMPLES OF RELATIONSHIPS BETWEEN PRECIPITATION AND SURFACE WATER IN WEST AFRICA

Related variable	Nature of relationship (+ indicates positive correlation; - indicates a negative correlation)	Example
Runoff	+ Runoff decreases as rainfall decreases	Niger and Lake Chad basins (Milly et al., 2010)
	No steady correlation	1961-1990 (De Stefano et al., 2010)
	+ Runoff decreases as rainfall decreases	Niger, Volta, Comoé, and Bandama rivers located in Burkina Faso, Côte d'Ivoire, Guinea, Mali, and Niger (Dezetter, 2008)
	- Runoff increases as rainfall decreases (Sahelian paradox, Descroix and Amogu, 2009)	Certain right-bank ¹¹ tributaries of the Niger and the Nakambé at Wayen (Dezetter, 2008)
	- Runoff increases as rainfall decreases (Sahelian paradox, Descroix and Amogu, 2009)	Sahelian tributaries of the Niger River, namely the Sirba, Gorouol, and Dargol (Amani and Nguetora, 2002); and, to a greater extent, the Nakambé River, a tributary of the Upper Volta (Mahé et al., 2005)
	- Runoff increases as rainfall decreases (Niamey paradox)	Niger Basin: decreases in rainfall actually occurred alongside increases in runoff due to soil erosion and crusting, resulting in large part from

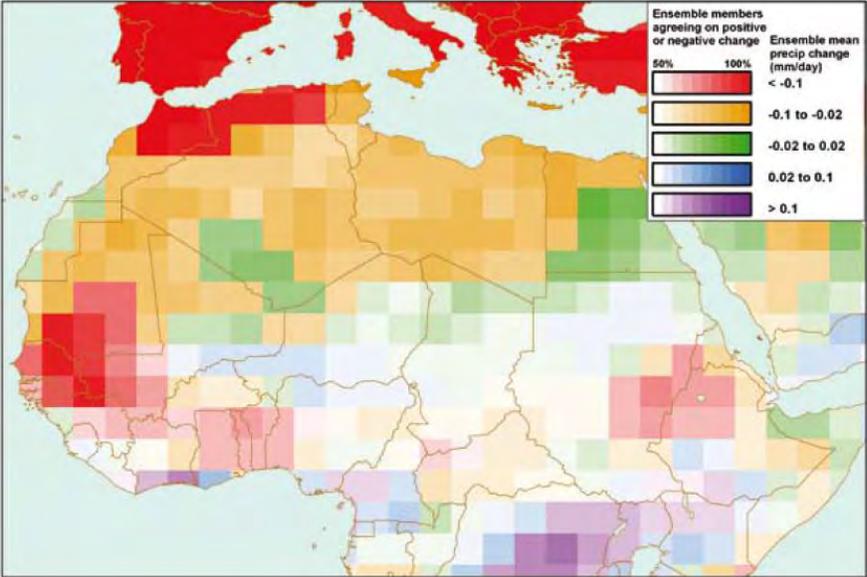
¹¹ From the perspective of looking downstream.

Related variable	Nature of relationship (+ indicates positive correlation; - indicates a negative correlation)	Example
		human activities (Descroix and Amogu, 2009)
Discharge	+ Discharge decreases as rainfall decreases	Sudanian regions: along the Ouémé River and certain tributaries of the Niger River (Alibori, Sota, Irané, and to a lesser extent, the Mékrou, Tapoa, Goroubi, and Diamangou) (Descroix and Amogu, 2009)
Drainage	2050: No change as rainfall increases	Areas receiving less than 400 mm/year (most of the Sahel) will not encounter an increase in drainage as a result of marginal increases in precipitation (Wit and Stankiewicz, 2006)
	2050: Drainage decreases faster as rainfall decreases	Southern belt: areas receiving 1000 or fewer mm/year (Wit and Stankiewicz, 2006)

3.2.3 Future Precipitation and Its Relation to Surface Water Supply

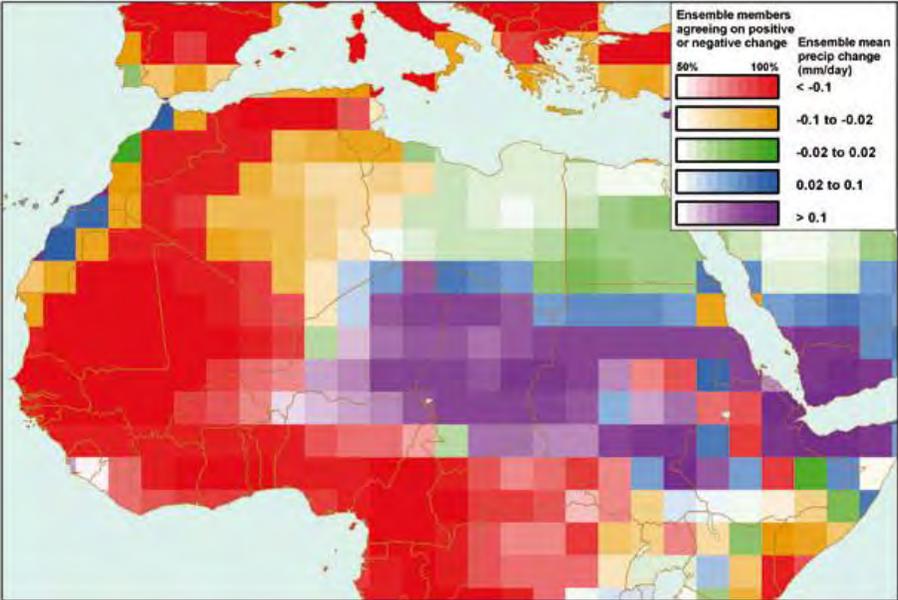
Some uncertainty still reigns in regards to future precipitation in West Africa. Rainfall projections across the region indicate how certain atmospheric processes, particularly the behavior of the West African Monsoon (WAM) and African Easterly Jet (AEJ), could lead to slight humidification, particularly in the eastern stretches of the region, with a stationary tendency along the Guinean coast (OECD, 2008; Vigaud, Roucou, Fontaine, Sijikumar, and Tyteca, 2011). On the contrary, the coastal countries of the western Sahel around the Senegal River Basin and part of the Niger River Basin are expected to see a reduction in precipitation of approximately 0.1 mm/day during the rainy season (June, July, and August) in 2041-2070 as compared to 1960-1990, while central and most of the eastern Sahel will see an increase in precipitation (0.02 to 0.1 mm/day) during the summer (OECD, 2010). Figures 12 and 13 show the level of agreement between different models in two separate ensembles. Figure 12 reflects greater agreement between models on the extent of precipitation change in the region.

FIGURE 12. DIFFERENCE IN SUMMER PRECIPITATION BETWEEN 2041–2070 AND 1960–1990 ACROSS AR4 ENSEMBLE



Note: The color indicates the strength of the signal, while the color intensity indicates consistency across the ensemble. Source: OECD, 2010

FIGURE 13. DIFFERENCE IN SUMMER PRECIPITATION BETWEEN 2041–2070 AND 1960–1990 ACROSS MET OFFICE HADLEY CENTRE ENSEMBLE

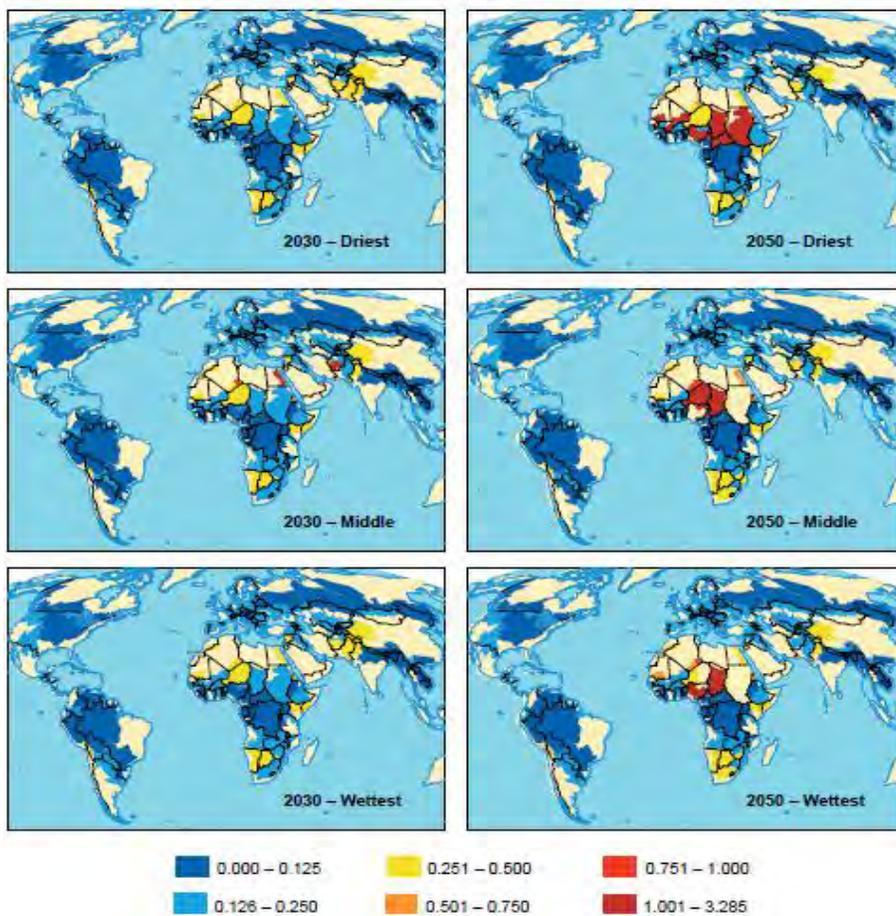


Note: The color indicates the strength of the signal, while the color intensity indicates consistency across the ensemble. Source: OECD, 2010

Oguntunde and Abiodun (2013) echo the OECD's (2010) projections of precipitation distribution; they predict that the western Sahel will become dryer than the eastern Sahel due to a strengthening of the WAM flow. They also claim that elevated greenhouse gases under the A1B climate scenario would create a drier climate during the rainy season (April to September) and a wetter climate during the transition months (March and October) in the Niger River Basin from 2031 to 2050.

Similar to past observations, projections of precipitation and surface water supply show no consistent correlation between the two over time and space. De Stefano et al.'s (2010), for instance, project trends in precipitation and runoff for dry, medium, and wet scenarios. They assert that there is no consistent change in the CV ranging from either dry to wet, or from 2030 to 2050. Figures 14 and 15 below depict these projections at the global level, showing relatively high CVs for West Africa. The study underscores the medium scenario as the most likely outcome; this scenario is also based on the A1B emissions scenario of the 2007 IPCC report.¹²

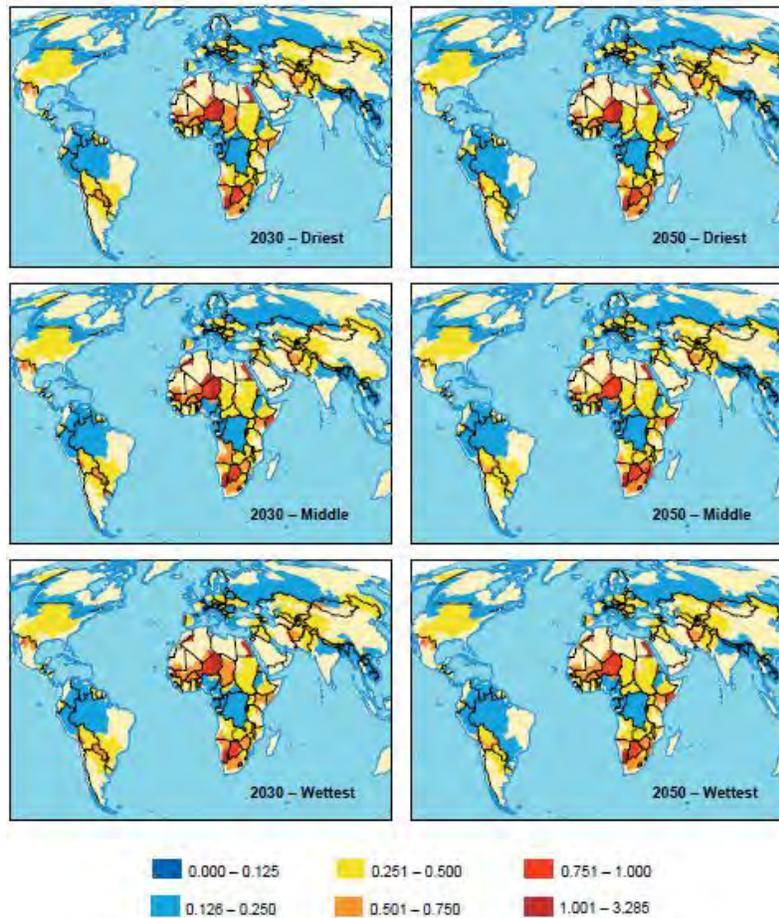
FIGURE 14. GLOBAL DISTRIBUTION OF PROJECTED CVs IN PRECIPITATION FOR 2030 AND 2050 FOR DRIEST, MIDDLE, AND WETTEST SCENARIOS



Source: De Stefano et al., 2010

¹² For more information on the IPCC climate scenarios, please visit this website: http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wgl/029.htm.

FIGURE 15. GLOBAL DISTRIBUTION OF PROJECTED RUNOFF CVS FOR 2030 AND 2050 FOR DRIEST, MIDDLE, AND WETTEST SCENARIOS



Source: De Stefano et al., 2010

Doell & Schmied (2012), who explore the relationship between runoff and river flow regimes by assessing the impacts of climate change on both, present a similar thesis. At large spatial scales, they find that the impacts of climate change on river flow regimes generally follow changes in projected climate change impacts on Mean Annual Runoff (MAR). At the sub-basin level, however, climate change impacts on flow regimes vary depending on the upstream or downstream location of the river. These findings underscore the significance of spatial scale in assessing basin vulnerability to climate change.

Similarly, Wit and Stankiewicz (2006) identify a non-linear relationship between perennial drainage density and mean annual precipitation. Using precipitation projections for Africa until the end of this century, they claim that a moderate but variable change in precipitation by the latter half of this century would alter surface water levels in Africa. Using a multi-threshold model, they predict that areas in West Africa receiving less than 400 mm of precipitation per year (most of the Sahel) will not encounter an increase in drainage as a result of marginal increases in precipitation. However, the southern band of West Africa would be notably influenced by changes in rainfall. For example, a 10-percent decrease in annual rainfall would reduce drainage by 17 percent for areas receiving 1000 mm per year, while the same decrease would reduce drainage by 50 percent in regions receiving only 500 mm per year. This finding again signals greater vulnerability of river basin areas located in the Sahel as compared to those located in the more humid southern regions.

In general, a positive correlation between precipitation and runoff (as a proxy for surface water supply) can be assumed to hold true in most cases, especially at the basin scale; however, this relationship is sometimes inversed due to changes in land cover. It should also be noted that some degree of uncertainty prevails concerning the region's future climate due to the inability of the various General Circulation Models (GCM) in use to accurately simulate precipitation in the Sahel; this finding is truer for rainfall than for temperature. One complicating factor for modeling is the extreme variability of the twentieth-century climate in West Africa (the baseline for model projections), which renders it difficult to pinpoint a signal attributable to climate change (OECD, 2008). For example, Arnell and Goesling (2013) indicate that for West Africa, there is a very high level of uncertainty for the percentage of change in regional runoff by 2050, and that more than 97 percent of the variance in estimates is due to model uncertainty. This uncertainty, they claim, results more from differences in the spatial pattern of the various models used than from differences in climate sensitivity.

Globally, there is a nonlinear relationship between climate and the availability of freshwater resources in the TRBs of West Africa. This assertion is based both on the historical record and future projections and is due to compounding variables related to site-specific land use/land cover change.

3.3 TEMPERATURE AND SURFACE WATER SUPPLY

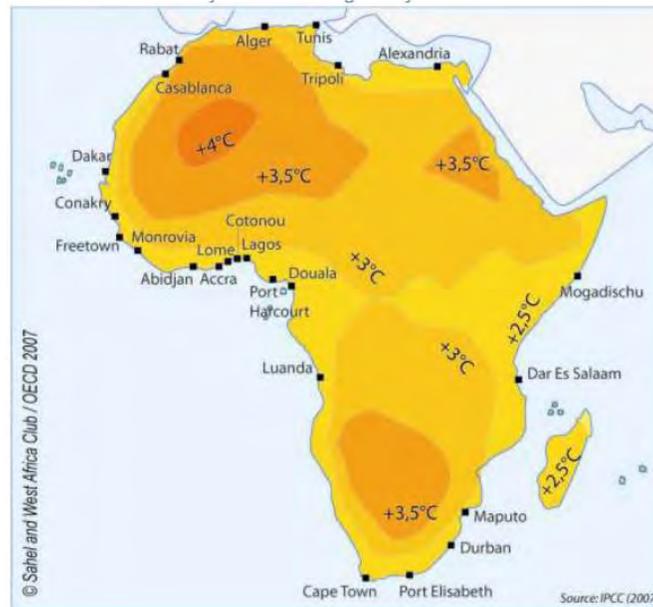
3.3.1 Historical Temperature and Surface Water Supply

Compared to precipitation, there is far less literature on the relationship between temperature and water supply due to the lack of direct correlation between the two. Rather, temperature mediates the relationship between precipitation and surface water supply (or runoff and discharge) via evaporation (Thiam & Singh, 2004). As such, climatologists still disagree about the observed impacts of temperature on surface water supply, especially climate change-induced temperature increases. For example, Labat, Godd ris, Probst, and Guyot (2004) claim that an increase in temperature of 1 °C during the twentieth century led to a 4-percent increase in global total runoff; other scientists, however, challenge this finding in light of the effects of non-climatic drivers on runoff and related variables (Legates, Lins, & McCabe, 2005).

3.3.2 Future Temperature and Surface Water Supply

Climate projections for the region suggest that temperature increases in West Africa are likely to be higher than the global average (IPCC, 2007). In fact, the IPCC anticipates that West Africa's temperature will rise between 2 °C and 4 °C by the end of the century. It should be mentioned that half of the models used for the IPCC AR4 projections agree on an increase of 0.5 °C from the median values for the entire region (Christensen, Hewitson, Busuioc, Chen, & Gao, et al. 2007). Disaggregated spatially, the greatest warming estimates (~4 °C) are likely to occur over land and in particular in the western Sahel, while the southern coastal areas should experience a temperature increase of 3 °C. Warming trends, therefore, are expected to be highest for the Senegal, Gambia, western Niger, and Upper Volta River Basins. Temporal projections indicate stronger warming occurring during the summer months (Oguntunde & Abiodun, 2013). Figure 16 below shows temperature projections for the 1980-1999 period as compared to the 2080-2099 period in West Africa and other regions of Africa.

FIGURE 16. TEMPERATURE PROJECTIONS IN AFRICA FOR THE 2080-2099 PERIOD COMPARED TO THE 1980-1999 PERIOD



Source: OECD, 2007

In West Africa, the impact of temperature on TRBs is expected to vary across time and space. For one, a reduction in peak precipitation is predicted to cause a decline in surface runoff for the Niger River Basin as a whole (Oguntunde & Abiodun, 2013). This positive linear correlation between precipitation and runoff seems intuitive. However, as revealed above in the section on historical rainfall-runoff relations, the connection between climate and water supply at the sub-regional scale is predicted to be anything but stable due to confounding variables, mostly related to land cover change in different locations (Oguntunde & Abiodun, 2013).

3.4 EXTREME CLIMATE EVENTS

In West Africa, climate change is expected to increase the frequency of extreme events like floods and droughts. As explained above, the twentieth-century drought in West Africa caused declines in freshwater availability. With medium confidence, the IPCC (2007b) defines this drought as an extreme event and, with low confidence, attributes it to anthropogenic climate change (IPCC, 2012). Furthermore, extreme events like rainfall intensity and flooding have been shown to reduce water quality, and this trend is expected to rise in West Africa in the future (IPCC, 2012).

In addition, scientists have determined that a projected increase in the frequency of flooding and heavy rains will bring about land cover changes detrimental to runoff. Specifically, these events are expected to produce widespread erosion and siltation along each of Burkina Faso's four basin slopes. Together with projected declines in rainfall, by 2050 runoff is expected to decrease at various rates, ranging from 29.9 percent in the Nakanbé basin to 73 percent in the Mouhoun basin (Brown & Crawford, 2008). As a whole, it is expected that extreme events will exacerbate the aforementioned feedbacks between climate, ecology, and hydrology. However, given the present uncertainty about the extent and location of these connections, further research pertaining to their effects on West African rivers is needed.

Another unexplored research topic is the impact of fires on water supply since, theoretically, fire-induced declines in vegetation would also increase runoff, all else being equal.

3.5 CLIMATE AND WATER QUALITY

Globally, water quality highly correlates with changes in climate and the spatiotemporal variation of flow regimes (Nilsson et al., 2008). Other factors, such as altitude, geology, instream physical habitat complexity, streamside wetlands and riparian areas, and connectivity with the floodplain can influence water quality along rivers (Vannote et al., 1980; Newbold et al., 1982). Moreover, processes such as seasonal trends, underlying geology and hydrology, and human activities (including domestic, agriculture, industry, and environmental engineering) are the most dominant drivers of water quality (Pan Africa Chemistry Network [PACN]).

As such, extricating the impacts of climate change on water quality from this plethora of other factors proves extremely challenging. However, what is generally known about this relationship is that increases in temperature, fluctuations in precipitation, sea-level rise, and extreme events may diminish freshwater quality, especially in coastal areas (National Adaptation Plan of Action [NAPA], n.d.). For example, temperature increases may increase bacteria in surface water basins (United States Environmental Protection Agency [EPA], n.d.), and abrupt increases in river flows as a result of intense rainfall events or flooding are likely to compromise water quality in river basins. However, there is a lack of evidence pertaining to these feedbacks for West Africa, and further research on these connections is recommended.

The encroachment of invasive species is harming water quality in West African TRBs as a result of changes in both climate and river basin management techniques. In the Senegal River Basin, for example, flow regime changes resulting from dam-driven flood simulations have decreased salinity levels, allowing the *Typha* weed to thrive (Global International Waters Assessment [GIWA], n.d.). This plant pollutes water resources, thus threatening the fish, human, and livestock populations that depend on them. *Typha* weed also blocks irrigation canals and obstructs physical access to river resources; it also has been correlated with increases in malaria and Bilharzia infections, to name only a few of its destructive consequences (Elbersen, 2005).

This issue casts light on an unfortunate feedback loop between river basin management, climate, and ecology: that the dams created in part to mitigate the threats of the twentieth-century droughts on river basin ecology and livelihoods were the very culprits for the changes in salinity, spawning invasive species encroachment and further risks to ecosystems and livelihoods. *Salvinia molesta*, which pollutes and deoxygenates river water, is another species that has infested both the Niger and Senegal basins (Niasse, Afouda, & Amani, 2004; UNEP, 2010). Furthermore, *Eichornia crassipes* (water hyacinth) has invaded numerous water systems in West Africa, including the So and Ouémé rivers and Lake Nokoue in Benin; the Tano Lagoon and Accra/Tema water areas in Ghana; the Tano Lagoon, Comoé River, and Ono Lake in Ivory Coast; and the Niger River in Mali, Niger, and Nigeria (FAO, 1995). This species can completely cover water sources, thus altering flow and blocking sunlight. It also deoxygenates water, which can kill animal species. Additionally, like the *Typha* plant, it attracts mosquitoes, the vectors of numerous infectious diseases.

The hydrological and ecological threats outlined above illustrate the difficulty of distinguishing the impacts of climate change from those wrought by dams and other hydroelectric and hydroagricultural infrastructure. The latter interventions have been shown to reduce freshwater resources linked to modifications in the observed river regimes as well as to the deterioration of water quality and the lowering of the groundwater table (UNEP, n.d.). As advised above, we recommend further research to parcel out the connections between climate, ecology, and technological intervention as related to water supply and quality. These feedbacks will be further addressed in Chapter 4 in terms of their relevance to livelihoods and river basin management.

3.6 CLIMATE CHANGE AND RIVER ECOSYSTEMS

Ecosystems contribute significantly to biodiversity and human well-being in the transboundary river basins of West Africa (Biggs et al., 2004; Muriuki, Njoka, Reid, & Nyariki, 2005). In terms of global vulnerability, West Africa is expected to face the highest level of risk for ecosystem change by the 2069-2098 period as compared to 1961-1990 period — especially in the Sahel, which is expected to undergo severe change in vegetation structure, function, and productivity (Heyder, Schaphoff, Gerten, & Lucht, 2011). But ecosystems in West Africa and elsewhere are threatened by climate variability and other stresses not unrelated to climate, such as fire, invasive species, and land use change. As noted above, river basin flooding can create ecological conditions conducive to the proliferation of invasive species that can further alter ecosystem structure and function. Other facets of the ecosystem suffer similar damage due to climate change, including fish habitats, ecosystem structure, and coastal environments.

3.6.1 Fish Habitats

Invasive species can also alter the biological cycle of fish populations; however, invasive species often have been shown to buffer fish populations from extractive activities insofar as they obstruct access to rivers. In 2005, Lae, Williams, Massou, Morand, and Mikolasek conducted a study on fish habitats and fisheries in the Niger River. Their findings show a number of changes in fish populations from 1968 to 1989. For example, fish landings were halved and central and large-sized species became extinct, only to be replaced by small-sized and more productive species; however, the number of species (260) did not change. Lae et al. attribute these changes to alterations in flora and fragmentation or destruction of normal fish habitats as a result of the following three processes: the building of dams, pump irrigation into river perimeters, and drought conditions. They do not, however, indicate the weight of each of these variables in modifying fish habitat, composition, and population (Malam & Mikolasek, 2004).

3.6.2 Ecosystem Structure

In West Africa, ecosystem degradation has taken the form of foreign species invasion, deforestation, erosion, and a decrease in soil quality and vegetation productivity. These effects further exacerbate the impacts of climate variability and change. According to Boko, Niang, Nyong, Vogel, Githeko, et al. (2007), West Africa has undergone a transformation in ecological structure as a result of rainfall decline. Specifically, between the 1970s and 1990s, the Guinean, Sudanian, and Sahelian eco-zones each shifted southward by 25 to 35 km (Gonzalez, 2001). This spatial shift has been accompanied by displaced sand dunes in the more arid zones of the north alongside losses of fauna and flora, namely grasses and acacia trees, in semi-arid zones (ECF and Potsdam Institute, 2004). Such declines in vegetation productivity can increase runoff, which may lead to greater surface water supply in TRBs; however, they also can weaken local precipitation regimes and thus have a counteractive effect on water supply (Descroix et al., 2009).

3.6.3 Coastal ecosystems

In West Africa, rising sea levels due to anthropogenic climate change threaten coastal biotopes (beaches, lagoons, swamps, etc.) (OECD, 2008). This threat includes the coastal perimeters of TRBs and their deltas. Figure 17 on the following page shows the general repercussions of projected sea-level rise by 2100, including submerged land, surface loss through erosion, and costly damage to property.

FIGURE 17. IMPACTS OF SEA LEVEL RISE IN 2100

	Submerged surface area (sq. km)	Surface area lost through erosion (sq. km)	Value of property affected (millions of USD)
Senegal	1,650	28 - 44	345 - 464
The Gambia	46	-	-
Côte d'Ivoire	471	-	4,710
Benin	17.5	22.5	
Nigeria	8,864	78 - 145	9,003

Source: IUCN (2004) *Réduire la vulnérabilité de l'Afrique de l'Ouest aux impacts du climat sur les ressources en eau, les zones humides et la désertification*
 * Resulting from an increase in sea levels (0.5 m by 2100)

Source: OECD, 2008

Specifically related to TRBs, climate change-induced sea-level rise is known to attack mangroves (Field, 1995; Gilman, Ellison, Duke, & Field, 2008), which themselves are shown to mitigate the impacts of climate change by buffering river basins against waves and saltwater intrusion. Both of these are exacerbated by sea level rise as well as by protecting waterbirds and river fish stocks (Wetlands International, 2010).

Further amplifying the ecological effects of climate change is the mounting population pressure of West Africa's coastal areas. Boko et al. (2007) predict that the coastline between Accra, Ghana, and the Niger delta will become a continuous megalopolis of more than 50 million people by 2020 (Hewawasam, 2002). The projected rise in sea level will not only jeopardize human populations; when coupled with population density itself, it will also cause ecological stress in the form of species migration, pollution, natural resource degradation, and increased freshwater withdrawals from TRBs.

3.7 CONCLUSIONS

As we have attempted to demonstrate in this chapter, there is considerable intra-regional variation in both the temporality and spatiality of climate variability and change and their effects on the surface water resources of TRBs in West Africa.

A holistic grasp of the impacts of climate — both variability and change — on these basins demands an appreciation of the biophysical processes linking not only climate and hydrology, but also their relationship to land use/land cover change as a function of human activity and the biophysical effects of technological interventions and extreme events.

This inextricability of biophysical and anthropogenic factors in regard to climate and hydrology are perhaps best demonstrated in the literature on the twentieth-century Sahelian droughts. The most recent consensus blames the droughts on warmer-than-average Sea-Surface Temperatures (SSTs) in the Atlantic, Indian, and Pacific basins, which weakened the West African Monsoon (WAM) signal (Giannini, Saravanan, & Chang, 2003; IPCC, 2007). Shanahan, Overpeck, Anchukaitis, Beck, and Cole, et al. (2008) suggest that the weakening of the WAM may be more a result of changes in the AEJ than changes in solar radiation, or of the position or intensity of the Inter-Tropical Convergence Zone (ITCZ). Lu and Delworth (2005) defend the hypothesis of Giannini et al., but also suggest that the warming of the tropical oceans triggering the droughts could have been the result of anthropogenic aerosols. In an

TRBs most exposed to climate variability and change:

- Western Sahel: the Senegal, Gambia, Western Niger, and Upper Volta
- Central and eastern Niger Basin

attempt to reconcile the debates on natural versus anthropogenic change, Giannini, Biasutti, and Verstraete (2008) show that while SSTs play a dominant role in forcing the droughts, human-induced land cover changes may actually amplify SST forcings. As shown here, in assessments of climate and hydrologic change, the biophysical and the anthropogenic are best analyzed as a coupled system rather than as discrete factors.

Finally, this chapter has assessed the levels of exposure of West African TRBs to climate change. In summary, the authors assert that the basins of the Western Sahel — the Senegal, Gambia, Western Niger, and Upper Volta — to be the most exposed. This assessment takes into account the sub-region's historical and projected increases in temperature, declines in precipitation, and high levels of spatial and temporal variability. Of second-highest exposure is the central and eastern Niger Basin, where precipitation is expected to increase. While situation this may result in higher surface water availability in some areas of the basin, it will be offset in others due to rising temperatures (via evapotranspiration). Furthermore, increases in runoff may also negatively affect basins like the Niger by increasing flooding and reducing water quality, groundwater recharge, and basin capacity (as a result of increased sediment).

The following chapter extends beyond the biophysical foundations of TRBs discussed here to the socioeconomic factors that mediate the relationship between climate and water supply in TRBs.

4.0 CLIMATE IMPACTS ON RIVER BASIN-DEPENDENT LIVELIHOODS AND INDUSTRIES

This chapter discusses how climate¹³ and the other biophysical dynamics analyzed above influence livelihoods and industries that depend on TRBs in West Africa. To do so, the chapter addresses the following themes:

- Impacts of climate change on agriculture and fish production;
- Adaptation and coping mechanisms pursued in West African TRBs in response to climate change and other stressors;
 - Potential trade-offs associated with these mechanisms;
 - Potential impacts of these mechanisms on TRB surface water supply;
- Impacts of climate change on river-linked industries; and
- Disaster risk reduction and management in TRBs.

It concludes with the argument that the impacts of climate change on river basin-dependent livelihoods and industries are best assessed in conjunction with other factors such as population pressure and land cover change.

4.1 CLIMATE CHANGE AND RIVER BASIN PRODUCTION

4.1.1 Agricultural Production

Climate variability and change threaten natural resource-dependent livelihoods in West Africa, especially in the arid Sahel. Farmers, herders, and fishers relying on surface water are particularly vulnerable due to the climate-related depletion or contamination of these resources (UNEP, 2011). This degradation is expected to diminish agricultural and fishing yields in many parts of the region.

¹³ A note on terminology: Chapter 3 differentiated between climate variability and change in order to analyze the biophysical impacts of each on West African TRBs. However, beginning in this chapter and continuing through the remainder of the document, the authors employ the IPCC (2007) definition of climate change, which includes both natural variability and greenhouse gas-induced change.

Agriculture is the main activity for more than 74 percent of West Africa's population, playing a major role in the regional economy and constituting the region's main livelihood source (Dow, 2005). The most important food crops and cash crops grown in the region are cereals (sorghum, millet, maize, and rice); roots and tubers (cassava, sweet potatoes, and yams); and legumes (cowpeas, groundnuts, cocoa, coffee, and cotton) (Jalloh, Nelson, Thomas, Zougmore, & Roy-Macauley, 2013). Livestock production is another principle activity among agriculturalists. The agricultural sector absorbs around 60 percent of the active labor in West Africa and contributes 35 percent of the gross domestic product (GDP). The supply and quality of West Africa's TRBs thus play a crucial role in determining the livelihood security of farmers and herders alike. For more detailed information on the impacts of climate on agricultural production in West Africa, please see Annex C.

4.1.2 Fisheries

After agriculture, inland fishing is the largest economic activity in West Africa's TRBs. In the region's inland capture fisheries, which include lakes, rivers, lagoons, and aquaculture, production is artisanal and accounts for one-fifth of West Africa's total fish production, amounting to approximately 645,000 Metric Tons (MT) (Katikiro & Macusi, 2012; statistics based on FAO FishStat). In recent decades, dams in TRBs have threatened fish production. The Senegal River Basin, for example, has withstood a steady drop in fish production levels in Mali, Mauritania, and Senegal, mostly due to the negative impacts of dam development and the ensuing proliferation of aquatic weeds, salinization, and eutrophication¹⁴ (United Nations Educational, Scientific, and Cultural Programme [UNESCO], n.d.).

According to the FAO (2008), inland fisheries of West Africa may already be facing the detriments of climate change, which may in turn jeopardize the livelihoods of fishing communities. Such impacts include fluctuations in primary fish production and yield brought on by temperature increases (Katikiro & Macusi, 2012), declines in rainfall and surface water supplies, and other factors such as wind regime changes. One such example is found in Lake Chad, which occupies only 10 percent of the area it did in 1963 due to both climate change and increased withdrawals. As a result, the productive potential of the lake is declining (FAO, 2008). This decline highlights the influence of population pressure on river basin resources, which can be difficult to extricate from the impacts of climate. In fact, the FAO (2008) calculates vacillations in fish supply in West Africa as a function not only of projected climate, but also of population growth and market changes.

The section below shifts from the impacts of climate change on agricultural and fishing *production* to its impacts on *livelihood strategies*, the potential risks associated with these strategies, and their anticipated impacts on surface water supply.

¹⁴ The development of excess nutrients in water bodies, which can lead to excessive plant growth.

4.2 CLIMATE CHANGE AND RIVER-LINKED LIVELIHOOD STRATEGIES

In recent years, livelihood modifications in anticipation of and response to climate change have been studied at length, both in terms of coping and adaptation measures. The IPCC (2007) defines adaptation as “an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (n.p.). It recognizes several distinct types of adaptation, including anticipatory, reactive, and planned (based on a purposeful policy decision). On the contrary, maladaptation is recognized as the undertaking of a practice that makes people more vulnerable to changes in the natural environment (Brockhaus, Djoudi, & Locatelli, 2013). Such maladaptations are also known as negative coping mechanisms. Unlike adaptive strategies that refer to planned and frequently revised measures, negative coping mechanisms involve unplanned, reactionary, and localized measures in response to crisis, often to the long-term detriment of their practitioners (Brockhaus et al., 2013).

Different members of society have unequal access to adaptation and coping options. For example, the construction of dams or procurement of costly equipment is usually limited to governing bodies, private companies, or international organizations. There are other structural impediments in addition to these general economic and technical constraints on livelihood options. One example is culture; some activities mentioned in this chapter may be accessible only to one gender (Codjoe et al., 2012), such as savings and loan groups or gardening. In many areas of the region, only women pursue these activities. Others, such as diversification through the sale of wage labor or the pursuit of additional income-generating activities, may be amenable only to certain ethnic groups, classes, or castes. Thus, cultural appropriateness in adaptation programming is a key priority among riverine populations.

4.3 CLIMATE CHANGE AND RIVER-LINKED INDUSTRIES AND INFRASTRUCTURE

4.3.1 River-linked Value Chains and Markets

Climate change is expected to alter river-linked value chains, especially in terms of production (discussed in greater detail in Section 4.1.1), marketing, and distribution of agricultural and fishing goods. In particular, climate change is expected to affect the following links along the value chain:

Production and Processing

- *Disruptions in production and processing cycles* due to extreme events (flooding, drought, and fire); plant and livestock disease outbreaks; and climate-related ecological shifts (invasive species, changes in soil and surface water quality, etc.)

Marketing and Distribution

- *Socioeconomic obstacles to market access* due to decreased purchasing power brought on by climate-induced changes in production and income generation, especially for poorer populations
- *Physical obstacles to market access* due to climate-related transportation impediments (flooded or muddy roads, etc.)
- *Price fluctuations* due to climate-related changes in supply and demand

Value Chain Opportunities

Climate change, and the need for its mitigation, may continue to inspire the emergence or expansion of innovative markets in West Africa, such as biofuels; carbon markets; and fair trade, organic, and other

labeling schemes (Lamball, Nelson, & Nathaniels, 2011). Such opportunities will bring different benefits — or disadvantages — to different populations. Those with the information and capital necessary to invest in such schemes may profit from them, while poorer communities already lacking market access may become further economically marginalized by their exclusion from them. Such ventures are likely to link local producers to global value chains. Developing these linkages can strengthen the adaptive capacity and resilience of river-dependent farmers, herders, and fishers to climate change; nonetheless, they should be considered carefully in terms of the trade-off between boosting income security, specialization, and exposure to global market fluctuations (Lamball et al., 2011).

Thus, ensuring adequate access to credit and other financial services is essential for tackling vulnerability to climate change via value chain programming. One such strategy aimed at benefiting the rural poor in Ghana is the *Promoting Value Chain Approach to Adaptation in Agriculture* program. This effort, sponsored by the International Fund for Agricultural Development (IFAD), seeks to foster competitive, market-based commodity chains for root and tuber production among the rural poor, in part by connecting beneficiaries with funds for improved production and processing of crops (IFAD and the Global Environmental Facility [GEF], 2011). Development organizations may wish to consider supporting TRBMs in initiating such value chain programs in river basin-dependent communities in order to enhance small-scale farmer access to capital and increase resilience to climate change-related fluctuations in agricultural production.

Another accessible tool for strengthening river-dependent value chains is the use of the mobile phone, a virtually ubiquitous device in most parts of the region, to quickly relay information about opportunities and obstacles along value chains. The use of this technology to communicate market prices, stocks, opportunities and delays in transport, disease outbreaks, veterinary services, and more has already been widely adopted in West Africa, especially by pastoralists (International Institute for Environment and Development [IIED], 2010). Formalized programs supporting this technology also have been successful in other regions (All Africa, 2013). Mobile phone technologies present a key opportunity for development organizations to cultivate climate change-resilient value chains in West Africa, given the prioritization of programs that improve the efficiency of market transactions (Feed the Future, 2011).

4.3.2 Hydropower

Globally, climate change will increase demand for electricity and other fuel sources. This trend is no different in West Africa, home to a soaring population whose energy needs are likely to escalate with economic development and higher levels of consumption. Climate change is expected to compromise the function of hydroelectric dams in the region (France24, 2013). For instance, existing and planned hydropower projects for the Akosombo Dam of Lake Volta are predicted to perform at only 52 percent of capacity in 2050 and at 28 percent in 2100 due to reductions in water flows. Moreover, by 2050 only 75 percent of annual water demand for irrigation will be fulfilled, followed by only 32 percent in 2100. The six countries sharing the Volta Basin — Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali, and Togo — thus have been advised to diversify their energy sources by investing in renewable resources such as wind and solar (France24, 2013).

While hydropower dams fuel industries and households with essential energy supplies, they are also a source of negative social, economic, and ecological impacts. In addition to the ecological repercussions discussed in Chapter 3, the following grievances have been reported about hydropower dams in the Senegal River Basin. While not all of these apply universally to the TRBs of West Africa, most are emblematic of the types of problems that large dams in the region trigger (UNEP, DH-Center for Water and Environment, 2007; Pickaver & Sadacharan, 2007; UNESCO, n.d.):

Socioeconomic impacts

- Flooding of urban areas such as San Louis, Senegal
- Reduced water access for downstream users
- Reduced water access and transport capacity (both upstream and downstream) due to wind erosion and sediment deposits in the delta and the resulting formation of dikes
- Flooding in certain areas and severe water deficits in others during high flows
- Decrease in surface water quality
- Modification of groundwater recharge and the piezometric surface¹⁵
- Displacement of populations that once relied on a salty and brackish aquatic environment with clear seasonal changes and can no longer rely on the river's low-flow perennial freshwater ecology

Biophysical/Ecological impacts

- Reduction in fish populations due to increases in salinity and physical obstruction of spawning areas
- Loss of mangrove forests
- Shrinking of wetlands
- Flooding in certain areas and severe water deficits in others during high flows
- Decrease in surface water quality
- Modification of groundwater recharge and the piezometric surface

Nonetheless, and as emphasized in Chapter 3, none of these grievances can be blamed solely on the dam, just as the other ecological impacts identified in this report cannot be blamed solely on climate. An example of this interplay of confounding factors is the dwindling potential for recession agriculture in the Senegal River Basin, which is the complex result of erratic precipitation, controlled flooding regimes of the Manantali dam, population pressure, and land use/land cover change.

4.3.3 Irrigation

River-fed irrigation, also a major adaptation strategy in West Africa, is a largely infrastructure-dependent enterprise that diverts and regulates the flow of river water to farms and rangelands. Irrigation is becoming increasingly important in West Africa in light of climate change and other factors such as population growth and land use/land cover change. The major types include large-scale, dam-regulated irrigation for recession agriculture as well as small-scale irrigation using gravity-fed canals, mechanized pumps, and surface water harvesting (UNEP, 2011; Kiepe & Cotonou, 2006).

To date, irrigation remains an under-utilized mechanism for agricultural production. Rain-fed, rather than irrigated, agriculture is still the dominant form of subsistence farming and herding in the region, although it is only feasible in areas receiving 350 mm or more of annual rainfall (between approximately

¹⁵ The surface to which groundwater would rise if not trapped in a confined aquifer.

14 and 17 degrees latitude). In the nine countries of the Sahel,¹⁶ 46 percent of land area is agricultural (meaning it is under permanent crops or pastures). Nevertheless, only 5 percent of the total region's area is irrigated (UNEP, 2011).

Large-scale irrigation

The only dams supporting formal, large-scale irrigation are the Markala dam in Mali (Niger River); the Manantali dam in Mali (Bafing River, tributary of the Senegal River); and the Diama dam in Senegal and Mauritania (delta of the Senegal River). The Senegal River Valley, in particular, heavily relies on dam-regulated irrigation as the main driver of agricultural development, both for farming and livestock production. Approximately 100,000 acres of this river basin are cultivated via controlled recession agriculture (UNEP, 2011).

Small-scale irrigation

Pump and gravity-fed systems

Rural communities in TRBs rely both on mechanized pump and gravity-fed irrigation for small-scale agriculture. Based on field research that both authors conducted between 2008 and 2012 in the Senegal, Niger, and Lake Chad Basins, river-dependent communities largely prefer mechanized pumps as opposed to gravity-fed irrigation for three reasons: the former work more rapidly and efficiently than the latter, they can supply water during periods of low flow, and they can divert water to fields farther away from the river. Pumps can also aid in the equitable allocation of water to fields both near to and far from the river.

Where climate change is expected to reduce TRB surface water supply, demand for mechanized irrigation for small-scale production is likely to expand. It goes without saying, however, that many communities can afford neither to purchase a pump nor repair it if damaged. This situation was witnessed, for instance, in 2008 in a farming community in Mauritania, which had received a pump from a Japanese donor but was unable to maintain it due to lack of funds. The pump had been lying idle in the fields for one year at the time of the study. This anecdote reflects the potential trade-offs between low- and high-input technologies for rural small-scale agricultural communities that may lack the resources to obtain and maintain the latter.

Water harvesting

The majority of water sources used for irrigating agriculture in TRBs comes from rain and surface (rather than groundwater) sources. TRB communities located away from the river practice irrigation via surface water harvesting, collecting water using small-scale equipment rather than fixed infrastructure. Long practiced in rural West Africa, water harvesting is becoming increasingly popular in urban and peri-urban areas of TRBs (Graefe, Sonou, & Cofie, 2006). In recent years, these areas have attracted large rural populations seeking economic opportunities – itself an adaptive response to climate change. Climate change and increasing populations in both urban and rural areas of West African TRBs are likely to necessitate the expansion of rain and surface water harvesting for agricultural production and domestic use.

¹⁶ Burkina Faso, Cape Verde, Chad, the Gambia, Guinea-Bissau, Mali, Mauritania, Niger, and Senegal.

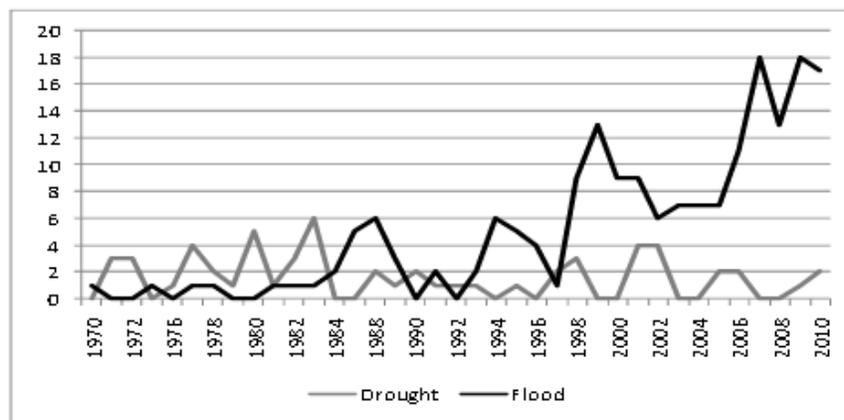
4.4 DISASTER RISK REDUCTION AND MANAGEMENT

This section relates the impact of natural hazards on riparian communities: flooding, mobility, and conflict. Floods were described above insofar as they affect biophysical ecosystems; here we explore their impact on riverine communities.

4.4.1 Floods

In West Africa, climate change and the runoff-enhancing effects of certain land use/land cover changes have resulted in greater frequency and intensity of floods in recent years. Figure 19 on the following page is a time series of the number of floods (and droughts) occurring during the past four decades in West Africa.

FIGURE 19. FLOODS AND DROUGHTS IN WEST AFRICA FROM 1970 TO 2010



Source: Independent Evaluation Group (IEG), 2010; based on data from EM-DAT, the International Disaster Database

In addition to these temporal trends, climatologists have identified geographic patterns of flooding in West Africa. Between 1985 and 2009, the sub-region suffering the most flooding (nine to 12 floods per year) was the central Sahel (its border is between Benin and Niger, southwestern Niger, northern Nigeria, and southern Burkina Faso). These peak trends were trailed by most of Burkina Faso, Southern Niger, northern Ghana, Benin, Togo, northern Nigeria, and southern Chad (seven to eight floods per year); and much of Mali, Mauritania, Ghana, Senegal, Benin, Niger, Nigeria, and Chad (five to six floods per year). The countries along the Atlantic coast, from the Gambia to Côte d'Ivoire, experienced the fewest incidents of flooding in the region (zero to two per year). Moreover, from 1995 onward, areas experiencing the most floods (between nine and 12 per year) have seen an increase in the frequency and spatial extent of this flooding. As a whole, flooding in the region endangers the health and lives of humans, animals, and other biota; it also reduces agricultural production (UNEP, 2011).

Furthermore, the expansion of West Africa's cities, coupled with the climate change-related increase in flooding episodes, poses a danger to urban populations. When urban growth expands over floodplains, a city becomes more vulnerable to flooding. To counter this, levees are sometimes erected; however, this equipment is prone to breaching, creating an even greater flood hazard for populations (ActionAid, 2006). In addition, projected sea-level rise, another impact of climate change, threatens coastal "megacities" in West Africa. Poor populations dwelling in highly concentrated urban areas are particularly vulnerable to this trend, which is expected to intensify flood hazards (IPCC, 2007).

According to a World Bank study on flooding response, collective measures that governments, donors, and civil society take to mitigate the impacts of flooding include the below short- and long-term interventions (IEP, 2010).

- Flood control measures (e.g., building flood control structures)
- Post-flooding short-term response (e.g., coordinated emergency response, rebuilding of vital infrastructure such as schools, social protection programs)
- Long-term flood prevention (e.g., soil stabilization and erosion control, natural resource management, and drainage systems for irrigation)
- Improvement of flood warnings (e.g., monitoring water level and flow velocity, installing warning systems, and implementing flood prevention policies)

4.4.2 Human Mobility

Climate variability and change are dislocating populations that depend on river systems in West Africa, particularly poor, subsistence-based communities. Flooding is a chief culprit of these displacements. In fact, from 2002 to 2012 alone, 7.5 million people were affected by floods in West Africa, and this rate is on the rise (European Commission [EC], 2012). In 2007, Mauritania declared a national emergency when thousands of homes were destroyed and many more people displaced due to extreme flooding. The city and surrounding areas of Kaedi, Mauritania, situated along the Senegal River, was evacuated with help from the national army. More recently, in late summer 2012, following two weeks of heavy rains, 81 people perished and 525,000 were displaced in Niger; Nigeria saw 137 deaths and 35,000 victims; and 25,000 people lost their homes in Cameroon (van Kote, 2012). Sedentary agriculturalists and agro-pastoralists dwelling in close proximity to a river are particularly vulnerable to flooding, though pastoral groups who rely on surface water resources are also at the whim of both flooding and drought (IIED and SOS Sahel UK, 2010), which can alter both transhumant and circulatory migration patterns.

However, similar to the discussions in Chapter 3 on the multiple causes of environmental vulnerability in the region, displacements resulting from flooding cannot be blamed solely on climate. In fact, flood-related damage, injury, and displacement may be attributed more to human factors — soil-crusting, land use changes, or poor drainage infrastructure, for example — than to heavy rainfall (van Kote, 2012). Inadequate or nonexistent early warning systems, preparedness, and disaster response mechanisms are additional factors. Flooding, other extreme weather events, and their effects should thus be examined holistically in terms of the assemblage of biophysical, socioeconomic, and political factors driving displacement in the region.

One additional note of interest about climate-related displacement in the region is the “integration arrangement” of the Economic Organization of West African States (ECOWAS), which permits free mobility within its borders to all its citizens (United Nations High Commissioner for Refugees [UNHCR], 2011). This arrangement may facilitate the integration of displaced persons into the societies of the receiving countries.

4.4.3 Conflict

Climate change impacts on natural resources, including river basins, are a less significant driver of conflict than is sometimes supposed. There is an apparent consensus within the international aid sector that climate change has and will continue to spur conflict over natural resources in West Africa (UNEP, 2011), including conflicts in TRBs (Brown & Crawford, 2008). At times, these views have been echoed by voices in academia (Barnett & Adger, 2007).

Undeniably, climate-related resource scarcity can strain vulnerable communities by contributing to price inflation, disease, and changing migration patterns, to name only a few examples. However, resource scarcity in West Africa, be it climate-related or otherwise, does not always culminate in increased competition or conflict (Watts & Peluso, 2001; Turner, 2004; Benjaminsen, 2008). In fact, heightened conflict has, at times, been observed alongside cases of resource abundance, not scarcity (Thiesen 2012; Butler & Gates, 2012). Moreover, countries weathering climate-related disasters such as droughts, floods, and storms have been shown to be less likely to face civil war (Slettebak, 2012). In rural Africa, climate-related resource availability and access, while important, are not the sole or even primary factors in explaining interpersonal or intercommunal conflict. Rather, institutional frameworks (Adano et al., 2012), property rights, and access to state resources (Butler & Gates, 2012) carry just as much, if not more, explanatory weight. Thus, the linkages between climate, resources, and conflict in West African TRBs are best understood as complex, contingent, and site-specific (Hendrix & Salehyan, 2012).

4.5 CONCLUSIONS

This chapter has explained how climate and other factors influence river-dependent livelihoods in West African TRBs. Documented changes in livelihoods are a product of climate change and other exacerbating factors, such as population pressure, hydrologic infrastructure, and land use/land cover change. The difficulty in isolating climate signals from other stressors is evident, for example, in the impacts of dams and other hydroelectric and hydro-agricultural infrastructure, which reduce freshwater resources and water quality. Another is the role of population pressure in reducing fish stocks, which can be difficult to distinguish from climate change-induced declines in river flows as they can produce an identical effect on fisheries.

The same is true for adaptation and coping strategies, which are never the result only of climate variability and change. Instead, they are undertaken in anticipation of and in response to a portfolio of socioeconomic, political, and environmental circumstances — often via careful planning and coordination. Moreover, livelihood activities vary in their purview of adaptation. Some, such as irrigation or community drains, are specific in scope and designed to bolster resilience by directly mitigating the negative impacts of climate change-related events like drought and flooding. Other strategies, such as livelihood transition or diversification, address the broader sources of vulnerability, such as gender inequalities, ethnic or class-based constraints, lack of political representation, and insufficient access to capital and credit, to name a few.

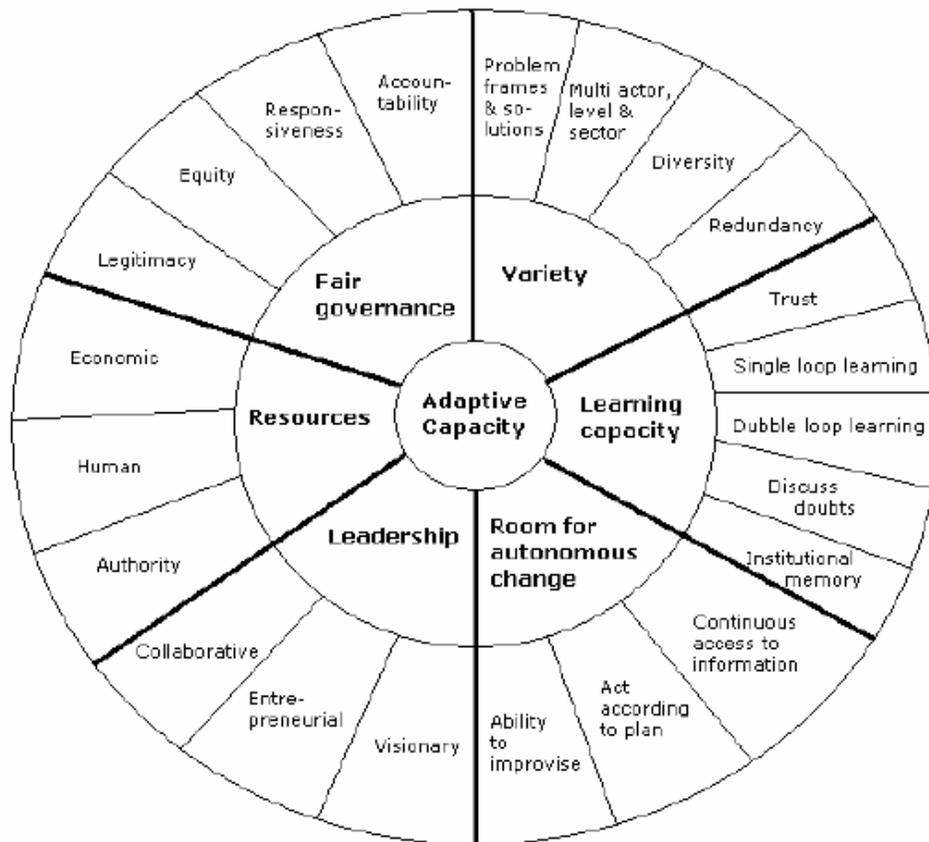
Similar to the challenge of isolating climate from the other drivers of livelihood change, it is difficult to differentiate the impacts of climate alone from the impacts of adaptation and coping mechanisms on surface water resources in West African TRBs. Nevertheless, this chapter has approximated the influence of these feedbacks and mechanisms on TRB surface water supply, as well as those of industries and infrastructure. These estimates may inform potential livelihood programming by shedding light on the trade-offs between adaptation practices and surface water demand.

5.0 ADAPTIVE CAPACITY OF INSTITUTIONS

5.1 ASSESSING ADAPTIVE CAPACITY

In this chapter we offer an assessment of the adaptive capacity of the five major West African TRBMs based solely on web resources. To conduct the review, we use the six dimensions of the Adaptive Capacity Wheel (ACW) (Gupta, Termeer, Klostermann, Meijerink, van den Brink, et al., 2010). These dimensions are fair governance, leadership, room for autonomous change, learning capacity, variety, and resources, and they comprise 22 associated criteria. The ACW is designed to measure the ability of an institution to foster the capacity of their constituents to respond to climate change and to shed light on the ways in which institutions may be reformed to increase this ability. The conclusions of this initial assessment are limited to the information upon which they are based and intended merely to serve as the foundation for further research.

FIGURE 20. THE “GUPTA” ADAPTIVE CAPACITY WHEEL



Source: Gupta et al., 2010

Caveats: This study is based on a secondary literature review, for which the vast majority of available material was obtained via the official websites of the management institutions themselves. As such, what follows is less of an assessment of these institutions' actual abilities to promote adaptive capacity, and more of an evaluation of their ability to share information through the Internet. As a result, the institutions with a clearer, more comprehensive web presence, especially those employing the vocabulary of climate change adaptation, were easier to assess within the framework. Such was the case of the VBA, which boasts a highly sophisticated website, thanks in part to the efforts of its collaborative partners. In contrast, it was next to impossible to assess OMVG, given the complete absence of a website and very few other sources of information. As such, we believe that further, preferable *in situ* research is needed to accurately assess the abilities of these institutions.

As a note of exception, the assessment of OMVS is far more detailed than the others due to the fact that one of the authors has worked extensively as a consultant for this organization and offers more intimate knowledge of its strengths and shortcomings. Other organizations may possess some of these same characteristics, though without the personal knowledge to substantiate them, no such judgments can be made. All views on OMVS in this chapter are those of the authors, unless otherwise noted.

5.2 NIGER BASIN AUTHORITY (NBA)

The NBA, despite its ungainly and somewhat outdated website, appears to be making strides toward the promotion of adaptive capacity within its member states. Its staff seems to be regularly engaged in workshops and plenary meetings, and to attend to the priorities of poor, river basin-dependent communities. However, the NBA appears to lack the funding necessary to achieve its objectives; one reason for this issue is the failure of member states to regularly pay their dues.

5.2.1 Fair Governance

To its credit, the NBA has democratized the most recent versions of its Water Charter and Sustainable Development Action Plan (VBA, 2008). The latter document underscores the Authority's primary objective of cooperation founded on solidarity and reciprocity in order to achieve sustainable, equitable, and coordinated use of water resources in the basin (VBA, 2008). Specifically, it outlines the needs to justly and expeditiously allocate water resources to all signatory states and more generally to make provisions for conflict resolution and negotiations. Thus, in theory, the NBA endorses fair governance, though further research is necessary to determine if this occurs in practice.

5.2.2 Leadership

As discussed in the following sections, NBA leadership does display a fair degree of *collaborative* will through its invitation of various stakeholders from government and civil society to participate in its plenary events. Furthermore, a recent article echoed the expressed commitments of its multiple leaders to collaborate with the Niger Ministry of Agriculture to realize its long-term *vision* of strengthening the basin's agricultural sector (LEADERSHIP, 2013) and becoming self-sufficient in terms of food production.

5.2.3 Room for Autonomous Change

One of the projects listed on the NBA's website is its Canadian International Development Agency (CIDA)-funded Capacity Building Project. This project commenced with an internal audit in 2005 that identified nine opportunities for capacity building within the organization (ABN, 2012a), which include reinforcement of technical, human resource, managerial, data management, and communications

capacity. Based on these results, CIDA has committed funds to address these areas of deficiency between 2010 and 2014. These activities reflect a *capacity to improvise*.

No information on databases, early warning systems, or disaster plans could be found, thus making it impossible to render an assessment of the other two criteria under this dimension — *continuous access to information*, and *act according to plan*. Assessing these dimensions would require field research.

5.2.4 Learning Capacity

In December 2011, a delegation from the NBA traveled to Senegal and Mali to meet with heads of OMVS to learn from their experience in navigation and irrigation management (ABN, 2001a). This effort indicates a commitment to institutional *learning*, and possibly also a willingness to *discuss doubts* about its own operations by comparing its own problems, lessons, and insights with those of another river basin authority. More recently, the NBA has organized meetings and conferences, such as the Heads of State and Government Summit, meetings of the Executive Secretariat, a regional workshop of the steering committee, and visits to individual member states (ABN, 2001a).

5.2.5 Variety

Evidence of the NBA being *multi-actor, multi-level, and multi-sector* is its Framework for Partner Cooperation. In 2004, 22 technical and financial partners convened in Paris to reaffirm their willingness to work together toward the development of the basin and to envision specific enterprises in the fields of fisheries, agriculture, energy, navigation, and more. Such events hold the potential to create space for a *variety of problem frames* and a *diversity of solutions* (ABN, 2011b). Apart from this example, no further information on variety could be found. This, too, is an area for potential further research.

5.2.6 Resources

In his opening speech delivered at a regional workshop in 2012, His Excellency Collins R. U. Ihekire, Major General of the NBA Executive Secretary, presented the organization's most recent strategic plan. Therein, he called attention to the *financial resources* collected via member state contributions, which make up 4 percent of the NBA's total budget. Specifically, he exposed the problem of late and absent financial contributions from the majority of its members, a problem he claims has stymied the Executive Secretariat's progress in implementing its strategic plan. For this reason, the NBA has been striving since 2009 to fulfill its goal of autonomous financing. As such, it has conducted several studies to investigate viable and sustainable means of generating revenue, through such means as levies, economic cooperation with other regional organizations, and the capitalization of funds (ABN, 2012b).

In terms of the professional development of *human resources*, there is a lack of information available to assess this dimension apart from a news feed about a workshop that NBA officials attended in Bamako in 2012. This event focused on developing the interior delta of the Niger River in the face of demographic pressure, climate change, and decaying infrastructure (ABN, 2012c).

5.3 SENEGAL RIVER BASIN DEVELOPMENT AUTHORITY (OMVS)

5.3.1 Fair Governance

In 1963, the precursor to OMVS was founded as the *Organisation des Etats Riverians du Fleuve Sénégal* (or the Senegal River Riparian States Organization) within the four riparian countries – Guinea, Mali, Mauritania, and Senegal. This organization dissolved upon Guinea's withdrawal due to political and

ideological tensions with Senegal. Then, in 1972, Mali, Mauritania, and Senegal formed OMVS, and Guinea joined in 2006 (Uhlir, 2002).

Under OMVS's mandate, the position of High Commissioner rotates every four years between appointees from Guinea, Mali, and Mauritania. The mandate excludes Senegal from this rotation under the logic that the headquarters is based in Dakar. In 2000, Mohamed Salem Ould Merzoug, from Mauritania, became High Commissioner. He then managed to remain in office for more than a decade through negotiation with Mali and then Guinea, whose turns to appoint a High Commissioner were bypassed. Although views on this may differ, this action suggests a weakness in the institution's governance processes, and perhaps a lack of *legitimacy* and *accountability* on the part of the organization. Merzoug resigned in early 2013 after the Mauritanian government allied with Guinea to put pressure on the other member states to call for a resumption of the mandated rotation. After Merzoug's resignation, Kabiné Komara of Guinea became the High Commissioner.

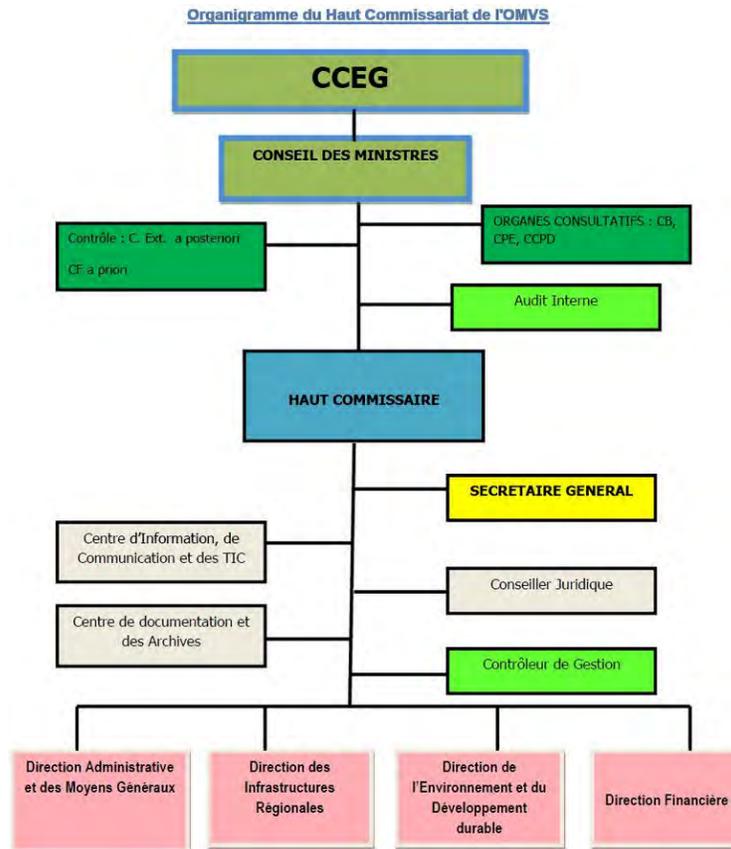
Changes subsequent to this transfer of power reflect characteristics of the organization that support the distribution of authority among member states. The representational structure of the OMVS shifts according to the country of origin of the High Commissioner. For example, if the High Commissioner is from Guinea, the directors of the three permanent management committees must hail from Mali, Mauritania, and Senegal. Moreover, the directors of the Management Committees for the two dams on the river, the Diama and Manantali, must not be nationals of the countries in which their headquarters are located, Mauritania and Mali. This and other foundational rules of the organization support a balance of power among the countries reinforcing its mandate for *equitable* representation.

Less evidence is available to demonstrate a high level of *responsiveness* to river basin-dependent populations on the part of OMVS. The organization has thus far been unsuccessful in addressing problems of highest concern for these groups, namely the invasion of the *typha* aquatic weed in the delta of Mauritania and Senegal (see Chapter 3) and problems associated with the flood simulation schemes (e.g., over- or under-flooding) that OMVS and the dam authorities impose to facilitate recession agriculture¹⁷ (Aaron & Newton, 2008). OMVS has been unable to commit sufficient resources to resolve these problems which threaten the livelihoods of millions of river-dependent people and weaken their capacity to withstand the impacts of climate change.

¹⁷ This assessment of the river basin inhabitants' prioritized concerns over the *typha* is based on research conducted in Mauritania and Senegal by both authors between 2008 and 2011.

5.3.2 Leadership

FIGURE 21. ORGANIZATIONAL STRUCTURE OF OMVS



Source: OMVS, n.d.

OMVS' Board of Advisors, consisting of the Ministers of Water Resources from each of the four member states, reviews the organization's mandate to ensure adherence (OMVS, n.d.). In a recent interview, High Commissioner Komara expressed his desire to produce more electricity for the member states, to renew hydrologic infrastructure, and to enforce the requirements regarding member state contributions (OMVS, 2013). These laudable intentions focus on important, macro-level institutional goals and issues. At the same time, however, the interview makes no mention of improving livelihoods in communities or strengthening local capacity to face climate change. Nor did the interview address agriculture and transportation, two the other critical components of OMVS' mandate. These lacunae suggest that, at least during this interview, these elements were not among Komara's core concerns. In the end, though not reflecting the broad range of the institution's authorities, Komara's words show *visionary* promise for OMVS to deal with long-standing issues related to energy production.

In terms of *collaboration*, OMVS has demonstrated its ability to undertake fruitful cooperative programs with other actors, such as its technical partner, the Compagnie d'Aménagement des Coteaux de Gascogne (CACG). Though this is the only partner mentioned on its website, OMVS has also collaborated with the University of Arizona and West African-based research bureaus. In recent years, donors have included the World Bank, GIZ, l'Agence Francaise du Developpement, African Development Bank, European Investment Bank, Islamic Development Bank, the Netherlands, Canada, and USAID, among others (OMVS, n.d.).

5.3.3 Room for autonomous change

OMVS scores relatively low for this dimension, as available information suggests a weakness of administrative organization, lack of continuity, and limited *capacity to improvise*. Staff do not have *continuous access to information* due to deficiencies in the systems to collect, store, and analyze data. In 2011, OMVS spent millions of dollars on advanced information and communications technologies (ICT) equipment, including servers and software, to process and store climatological, socioeconomic, agronomic, and geospatial data received from its technical partners. These data, which included 12 years of the Moderate Resolution Imaging Spectroradiometer (MODIS) 16 day-composite Vegetation Index and automated scripts for updating the data, were intended to be used for the remote sensing of flooding, fire, invasive species, agriculture, and vegetation dynamics in the entire basin. However, to date, this equipment is not being exploited as planned, and climate, socioeconomic, or agronomics are not being regularly monitored. OMVS has not instituted a functional early warning system or disaster plans, inhibiting its capacity to *act according to plan*. In cases of fire or flooding, the organization has no ability to warn vulnerable populations and their authorities in advance, nor can it respond to their needs once a hazard has struck or conduct useful research on, and learn from, such events.

5.3.4 Learning capacity

The organization's lack of data collection and auditing systems inhibit *institutional learning* and *memory*. Professional development does not seem to be fostered, as the institution does not financially support participation in trainings and conferences, and the publication of research is not encouraged. There also seems to be a lack of self-reflection in terms of assessing and strengthening institutional weaknesses.

5.3.5 Variety

At its inception, the member of states chose to adopt a multilateral approach to governing the river basin as opposed to adopting a unilateral model of management. This decision reflects their acknowledgement of the need for multi-actor, multi-level, and multi-sector engagements of the parties involved in the management and development of the river basin. Another institutional strength is the OMVS tendency to invite a *variety of problem frames* and a *diversity of solutions*, as evident through its multiple management committees and subcommittees that deal with a range of issues related to the development of the river basin. These include committees for navigation, environment, dams, technology, and communications, which convene regularly to discuss their differing viewpoints on organizational and operational challenges and potential solutions (OMVS, n.d.).

5.3.6 Resources

Evidence of corruption, in addition to the extended term of H.C. Merzoug, seem to have broken *trust* between officials in the organization. This is, in part, reflected in persistent and credible claims of nepotism and favoritism in the staffing of the institution, which undermine its scores for *legitimacy and authority*. As a result, the *human resource* base in OMVS does not accurately represent the member countries' experts from their respective fields and is weaker than it could be.

This is compounded by the lack of adherence to an employee performance review system to make decisions concerning staffing. Member states appoint officials, who, with the exception of the High Commissioner and directors of the permanent organs, usually stay in office as long as their governments permit them to, regardless of their performance. In terms of *financial resources*, OMVS relies on member state dues and donor investments. Evidence to demonstrate sound fiscal and compliance systems was unavailable.

5.4 VOLTA BASIN AUTHORITY (VBA)

Compared to the other four basin authorities, the VBA has a highly sophisticated website with detailed information about its structure, function, objectives, and programming. It also serves as a repository for data collected on the basin as well as program reports and summaries of conferences and meetings. This website facilitated a more in-depth assessment.

5.4.1 Fair Governance

The publication and web posting of VBA's protocols, decisions, and programmatic results suggests a high level of transparency in this institution's management. The VBA also publishes its bylaws and decrees on its website, thus facilitating their evaluation in terms of fair governance. Two features of its mandate relate directly to the Adaptive Capacity Wheel's criteria for *responsiveness* and *equity*:

- “Promote permanent consultation tools among the parties for the development of the basin;
- Promote the implementation of integrated water resources management and the equitable distribution of the benefits resulting from their various utilizations.” (VBA, n.d.)

Secondly, the website makes available the VBA's signed statutes (VBA, n.d.) — many of which speak directly to the need for *accountability* to the member states, to the inhabitants of the basin, and to the wider public. They also delineate the powers of the juridical unit of the VBA and the functions of its various organs.

5.4.2 Leadership

An internet search produced no direct information on VBA leadership. Thus, this study can only make crude inferences about the *vision*, *entrepreneurship*, and *collaboration* of its leaders. An example of the latter criterion may be the WANI project for improving water governance in the Volta River Basin (The International Union for Conservation of Nature [IUCN], n.d.). The aim of this project was to broker a compromise on water management between Burkina Faso and Ghana by hosting negotiations between multiple institutions and stakeholders to resolve transboundary conflicts and promote collaborative management of the basin. This goal seems to highlight the potential of the organization to promote adaptive co-management of the basin; however, apart from this example, further research is needed to assess the organization's leadership.

5.4.3 Room for Autonomous Change

The GLOWA Volta Project, sponsored by the German Federal Ministry of Education and Research and implemented from 2003 to 2009, was a multi-faceted, multi-partner research initiative aimed at assessing the physical and socioeconomic features of the Volta Basin's hydrologic cycle in the face of global change, and at developing scientific Decision Support Resources to improve regional management of the basin. To date, GLOWA offers a website and data portal (“Global Change and Hydrological Cycle in the Volta Basin,” GLOWA Volta, n.d.) showcasing information about the project's research, including meteorological and hydrological data, interactive maps and graphics, case studies, dissertations, and more. These resources supplement the VBA's own website, which houses multiple information and data archives. Together, these sites help ensure *continuous access to information* to inform decision-making and response, two of the criteria for autonomous change.

Furthermore, the GLOWA Volta Project oversaw a subsidiary effort known as the Sustainable Development of Research Capacity in West Africa (GLOWA, 2010). Three pillars of sustainable

development buttressed this project, namely the development of human capital, infrastructure and technical capacity, and institutional capacity building. These objectives clearly signal the project's commitment to VBA's *capacity to improvise*. One of the tasks of this project was to develop mechanisms for the early detection of the rainy season, which, when disseminated properly, can help agricultural ministries, extension offices, and producers plan production cycles and maximize yields.

5.4.4 Learning Capacity

This dimension was more difficult to evaluate due to limited availability of information. While the VBA website does furnish documentation of its project outcomes, meeting minutes, baselines, event summaries, etc., access to these documents is restricted to VBA personnel. Nonetheless, this finding may suggest a potential capacity for *single or double loop learning* in light of the organization's ability to quickly and easily review its own archives (VBA, n.d.).

5.4.5 Variety

Especially in terms of the GLOWA Volta Project, the VBA appears to have a *diversity of solutions* in its programmatic portfolio, as evidenced by the programmatic arms of the project and its multiple *problem frames* through which it can diagnose and treat problems related to the management of the river basin (VBA, 2012).

5.4.6 Resources

VBA seems to have ample *financial resources* through its numerous partnerships with donors, aid organizations, and research institutes (VBA, 2011). In terms of *authority*, its institutional rules are ostensibly couched in conventional laws (VBA, 2011). Unfortunately, no specific information was found on its *human resources*, namely the expertise, experience, and education background of its personnel.

5.5 LAKE CHAD BASIN COMMISSION (LCBC)

5.5.1 Fair Governance

The Lake Chad Basin Commission was established in 1964 by its four riparian countries – Cameroon, Chad, Niger, and Nigeria. It was joined by the Central African Republic in 1994. The commission strives to fulfill its mandate, as listed below:

- Sustainable and equitable management of the Lake Chad waters and other transboundary water resources of the Lake Chad Basin
- Preservation and protection of catchment area ecosystems
- Promotion of integration, and preservation of peace and security in the basin (Lake Chad Basin Commission (LCBC, n.d.)

Fair governance of the LCBC is without a doubt the most difficult dimension to assess. Based on the literature and online review, we are unable to make an informed statement about the overall capacity of the Commission to fairly govern the basin's territory, resources, and population.

However, our search did uncover what may be a single illustration of its capacity for fair governance. During the May 2013 LCBC Council of Ministers in Abuja (Abutu, 2013), member state leaders pledged to recharge the lake over the next two to three years with the goal of reducing poverty in the region.

The Council also mentioned its priority of improving the lives of the basin's communities, thus indicating some level of *responsiveness* to the needs of its constituents, at least in parlance. However, apart from this single anecdote, the authors are unable to make an informed statement about the other three criteria of this dimension: *legitimacy*, *equity*, and *accountability*.

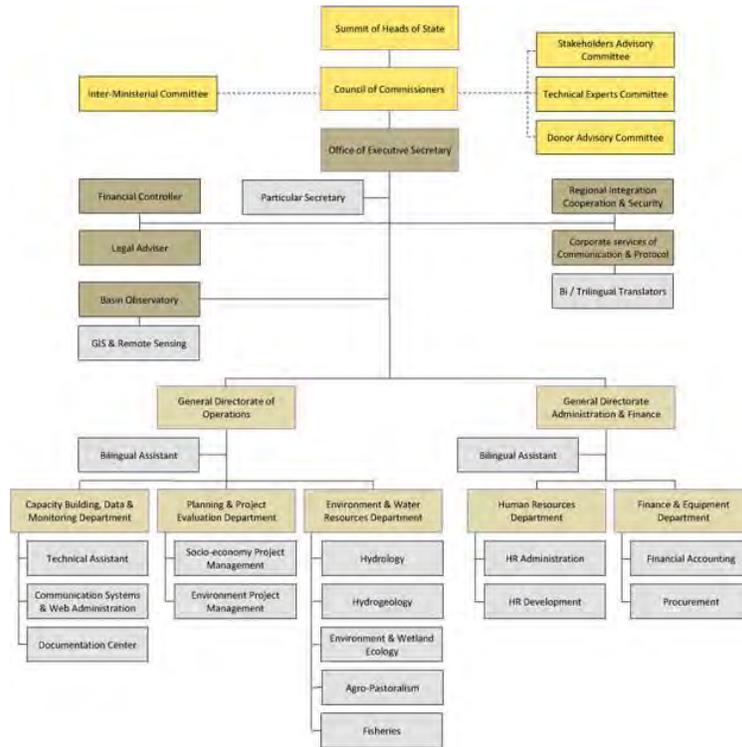
5.5.2 Leadership

One remarkable feature of the LCBC is its apparent commitment to engaging multiple stakeholders in the decision-making process and management of the basin. We see this commitment in its multiple consultative committees, including the Donors Committee, the Inter-ministerial Committee, the Committee of Stakeholders, and the Committee of Experts. These units, composed of external advisors, meet with the internal bodies of the commission deliberate and plan its management and development activities. This effort seems to illustrate the collaborative nature of the Commission's leaders (Abutu, 2013).

Another fact of interest is that the Commission's Executive Secretary, Sanusi Imran Abdullah, was rewarded for his dedication to justice and transparency by being appointed to serve as the Head of the Anti-Corruption Unit of the Hadejia Jama'are River Basin Development Authority from January 2000 to July 2005 (LCBC, n.d.).

The Commission's management structure, featured on the following page, appears more elaborate than that of the other management institutions, though this structure is not necessarily an indication of greater operational efficacy or efficiency.

FIGURE 22. ORGANIZATIONAL STRUCTURE OF THE LAKE CHAD BASIN COMMISSION



Source: Lake Chad Basin Commission, n.d.

Another indication of its *visionary* leadership is the Commission’s efforts to liaise with donors to secure funding. One such initiative involves the African Development Bank (ADB), which will hold a donor roundtable in September 2013 to raise money to fund the Commission’s five-year investment plan. Under this plan, the Commission endeavors to preserve the basin’s ecosystem and reverse its degradation by protecting food crops, improving the quantity and quality of its water resources, controlling pollution, and strengthening the capacity of its management (ADB, 2013).

5.5.3 Room for Autonomous Change

Reforms made after the institutional assessments of 2008 and 2009 (see *Learning Capacity*, below) call for the articulation of several guiding principles, one of which is flexibility, as defined below:

- “Anticipating the evolution of the Basin and knowing how to respond to emergency situations;
- Cooperating in order to render the capacities of the organization more flexible” (LCBC, n.d., n.p.).

From these statements, LCBC appears to have given some forethought to emergency and disaster response, and more generally, to its *capacity to improvise* its management style according to the emerging needs of the basin and its inhabitants.

5.5.4 Learning Capacity

In 2008 and then again in 2009, the LCBC undertook an institutional assessment of its own capacity and progress in meeting the objectives of its mandate. Based on the results of this assessment, the

organization revised its organizational structure, adding the following services to the office of the Executive Secretary: Basin Observatory, Financial Controller, Legal Adviser, Department of Corporate Services of Communication and Protocol, Department of Regional Integration, and Cooperation and Security. This action seems to demonstrate a capacity to discuss doubts about the present organizational structure and function as well as to address structural hindrances to success by learning from past experiences, if not also by modifying its assumptions underlying the patterns in its institutional processes. This self-assessment indicates capacity in the LCBC for *single-loop* and *double-loop learning* (LCBC, n.d.).

5.5.5 Variety

Indications of the Commission's *multi-actor, multi-level, and multi-sector* involvement include the following meetings the LCBC hosted:

- the Summit of Heads of State, the highest decision-making and advisory organ of the Commission that convenes member state leaders in a different capital city each year; and
- the Council of Ministers, made up of two commissioners per member state and charged with the supervision and control of the Commission; it formulates the annual budget and conceives the annual action plan.

In addition, the LCBC appear to have multiple technical partners, including the German Federal Institute for Geosciences and Natural Resources (BGR), the German Society for International Cooperation (GIZ), and the World Meteorological Organization (WMO); it is also party to the Ramsar Convention on Wetlands¹⁸ (LCBC, 2013).

5.5.6 Resources

As mentioned above, the LBCB appears to have a relatively elaborate *human resource* structure. Two general directorates (Operations and Administration and Finance) each oversee multiple technical departments and their respective sub-departments, as depicted in Figure 22 above. Moreover, the LCBC publicizes its fiscal management plan; its budget is finalized by the Council of Ministers and executed by the Executive Secretariat through the Directorate of Administration and Finance. Its budget for fiscal year 2013 is 16,620,096,250 FCFA – approximately 33,645,772 USD¹⁹ (LCBC, 2013); however, the website provides no indication of how these *financial resources* are being used, or if they suffice to carry out the Commission's strategic plan.

¹⁸ For more information, please visit the Ramsar website at http://www.ramsar.org/cda/en/ramsar-home/main/ramsar/1_4000_0__

¹⁹ Converted August 3, 2013.

5.6 GAMBIA RIVER BASIN DEVELOPMENT ORGANIZATION (OMVG)

A thorough internet search produced no official website for the OMVG; thus, the following chapters, which glean information from various web sources, are meager, and further research is needed to assess the adaptive capacity of OMVG.

5.6.1 Fair Governance

Compared to the conventions of other authorities, one remarkably *equitable* feature of the OMVG's *Convention Relating to the Creation of the Gambia River Basin* (International Water Law Project [IWLP], n.d) is its provisions for arbitration should an irreconcilable disagreement about OMVG's operations occur between member states. According to article 23 of the Convention, if discussion and mediation fail to resolve the disagreement, OMVG vows to engage the Commission of Conciliation and Arbitration of the Organization of African Unity. If mediation from the Commission fails to produce a mutually satisfactory outcome, then OMVG will seek the assistance of the International Court of Justice at The Hague.

5.6.2 Leadership

No information could be found on the capacity of the organization's leadership. It may be inferred, however, that the ongoing energy project financed by the ADB (see *Resources* chapter below) seeks to promote *collaboration* between member states in the pooling of resources and the equitable distribution of hydroelectric power (African Online News [AON], 2007). Still, it is unclear whether this directive came from OMVG's leaders, or if it was just a stipulation imposed by the ADB.

5.6.3 Room for Autonomous Change

Not enough information found to comment.

5.6.4 Learning Capacity

Not enough information found to comment.

5.6.5 Variety

In 2008, OMVG held a five-day meeting of experts in Kokoli, Senegal to discuss its priorities for development of the river basin. Rather than presenting a *diversity of solutions* to the challenge of developing the river basin, the leaders focused solely on hydroelectric power as its top development priority (Daily Observer Forward with the Gambia, 2008). To its credit, however, the meeting appears to have been *multi-actor*, *multi-level*, and *multi-sector*, as it brought together representatives of various government ministries, technical partners, and the private sector.

5.6.6 Resources

The OMVG appears to have an abundance of *financial resources* to develop its energy sector. In 2002, the ADB initiated plans to construct regionally integrated energy infrastructure in the Gambia River Basin. This project, costing USD\$180 million, consists of building two dams (Sambangalou in Senegal and Kaléta in Guinea) as well as an energy t-line feeding different regions of the basin with the hydroelectricity that the dams produce. The project also provides technical assistance to the OMVG, including provisions for

the assessment as well as monitoring and evaluation of the project. It is hoped that this infrastructure will help allay power cuts and an overdependence on foreign oil (AON, 2007). At the time of writing, it appears that the dams and t-line are still under construction (OMVG, n.d.).

6.0 CONCLUSIONS

6.1 CLIMATE CHANGE IMPACTS ON RIVER BASINS AND WATER SUPPLY

By the 2030-2050 period, changes in temperature and precipitation due to climate change will have variable impacts on surface water levels in different areas of the region. For instance, warming temperatures, ranging from 2.5 °C along much of the coastline to 4 °C in the northwestern Sahel (Christensen, Hewitson, Busuioc, Chen, Gao, et al. 2007) will likely exacerbate rainfall declines and hence decrease surface water supply in much of the western Sahel. However, this warming may be offset by rainfall increases in parts of the central and eastern Sahel. The impacts of precipitation on water supply are less predictable and will vary geographically. Areas in West Africa receiving less than 400 mm of precipitation per year (most of the Sahel) will not encounter an increase in drainage as a result of marginal increases in precipitation; however, the southern band of West Africa would be notably influenced by changes in rainfall (Wit & Stankiewicz, 2006).

This finding signals a higher level of climate change exposure for Sahelian basins than for those in other parts of the region. One study shows that by 2050, runoff will decrease alongside precipitation by 29.9 percent in the Nakanbé basin and by 73 percent in the Mouhoun basin, respectively (Brown & Crawford, 2008). Other studies show a higher degree of inconsistency (De Stefano et al., 2010) and uncertainty (Arnell & Goesling, 2013) for the projected links between precipitation and runoff, the latter of which does not always amount to increased or improved surface water supply. Adding to this uncertainty is a host of exacerbating factors, such as population growth, increased demand for hydropower and irrigation, and land use/land cover change.

In this vein, it is difficult, if not impossible, to isolate climate change signals from other stressors. Examples of this difficulty include: the reduction of water resources and quality due to hydroelectric and hydroagricultural infrastructure; the role of population pressure in reducing fish populations; and the adaptation of livelihoods due, alongside climate, to a variety of cultural, political, and environmental factors.

6.2 KNOWLEDGE GAPS

This study has identified knowledge gaps in the following thematic areas:

- Interactions between intense rainfall events, flooding, and water quality
- Correlations between land use/land cover change, runoff, river basin discharge, and groundwater recharge levels
- Impacts of extreme events on TRBs
- Links between fire and water supply (in consideration of the relationship between vegetation loss and increases in runoff)
- Pastoral migration to and through river basins and its effects on water supply

Moreover, the following gaps in knowledge represent key opportunities for development organizations to conduct future research to better understand the influence of climate change on TRBs in West Africa:

- **TRBMs:** There is a severe lack of literature on TRBMs in West Africa. A serious assessment of their adaptive capacity in light of climate variability and change can only be implemented through a thorough *in situ* study. Of priority for research are OMVG, OMVS, and NBA.
- **Smaller TRBs:** With the exception of the five major basins that formal institutions manage, the majority of TRBs in West Africa are poorly documented, and their connections with climate and other stressors poorly understood.
- **Fouta Djallon Massif of Guinea:** Five of the 11 TRBs in West Africa find their source in the highlands of Guinea. It is therefore critical to understand how these basins are working together, if at all, to manage transboundary hydrologic and ecological resources, as well as how climate, ecology, and human activities upstream are influencing water supply and livelihoods downstream.
- **Potential economic impacts:** Field research is needed to calculate the potential economic burden of climate change and other stressors on TRBs.

6.3 PRIORITIES FOR FUTURE RESEARCH

This study bases its recommendations for future research of West African TRBs on the following three criteria:

- Climate vulnerability
- Economic vulnerability (approximated as a function of population and spatial area)
- Need for improved adaptive capacity

6.3.1 Climate vulnerability

The evidence presented in this study suggests that among the major TRBs in West Africa, those in the Sahel are more vulnerable to climate change. This assessment takes into account the Sahel's exposure and sensitivity to climate change, as well as the adaptive capacities of its TRBMs, to the extent it could be assessed remotely. Of greatest vulnerability are those in the Western Sahel — Senegal, Gambia, Western Niger, and Upper Volta. Of second highest vulnerability to climate change is the central and eastern Niger Basin.

In terms of exposure, the Sahel is expected to experience the highest levels of intraregional spatial and temporal variability in temperature, precipitation, and runoff of anywhere in the region. Additionally, areas receiving less than 400 mm of precipitation per year (most of the Sahel) will not experience an increase in drainage as a result of marginal increases in precipitation. Within the Sahel, the western limits are expected to suffer the greatest increases in temperature, decreases in precipitation, and volatility in runoff of anywhere in West Africa. The second most vulnerable area — the central and eastern Niger River Basin — is likely to experience increases in precipitation and runoff. While this shift may result in higher surface water availability in some areas of the basin, it will be offset in others due to rising temperatures (via evapotranspiration). Furthermore, increases in runoff may also negatively affect the Niger by increasing flooding and reducing water quality, groundwater recharge, and basin capacity. (For more detailed information on climate and its influence on TRBs, please refer to Chapter 3.)

Livelihoods in Sahelian TRBs are also highly sensitive to climate change. River basin-dependent agriculture in this sub-region is primarily rain-fed. Soils are fragile, low in carbon and nutrients, and poorly managed. Fertilizers are not widely available; local crop varieties have poor yield potential; and pests, plant diseases, and weeds are rampant. Additionally, poor transportation infrastructure and market access limit the production and marketing capabilities of small-scale producers (UNEP, 2006).

Added to this are the low Human Development Index scores of the majority of West African Sahelian countries relative to those of other West African nations (UNEP, 2013), as well as the Sahel's high population growth rate (more than 3 percent) as compared to West Africa's as a whole (2.5 percent) (African Development Bank Group, 2012).

An initial, remotely conducted assessment of the five main TRBMs indicated that all institutions have some adaptive capacity, but likely need improvement. However, owing to the lack of detailed information on each and an inability to conduct research in the field, this assessment could not determine the true adaptive capacity of each individual institution.

6.3.2 Economic Vulnerability

It is also understood that for future research, development organizations may wish to prioritize the TRBs that stand to face the greatest economic strain from climate change and the battery of other stressors mentioned in this report. Field research is needed to better understand these potential economic risks. However, for the purposes of the present study, the population and spatial area of each of the TRBs can serve as proxies for the potential economic contribution of each basin. Table II lists these indicators for each TRB from highest to lowest value.

TABLE II. POPULATION AND AREA OF TRBs

Population (millions)	Area (km²) of TRBs
Niger – 106	Lake Chad - 2,434,000
Lake Chad – 37	Niger – 2,270,000
Gambia – 19.9	Volta – 400,000
Volta – 18.64	Senegal – 289,000
Senegal – 3.5	Gambia – 77,054

Industrial development may also serve as a proxy for potential economic contribution, though an evaluation of this contribution would require *in situ* research. For example, the Gambia River Basin, though higher in population than the Senegal and Volta River Basins, is the only basin that does not yet produce hydroelectric power; therefore, it may be at a lower risk of overall economic loss due to climate change and other factors. On the other hand, it may have much more to gain in terms of investment from development organizations. Another indicator would be the economic contribution of agricultural production in each of the TRBs. These data, however, could not be found at the basin level.

6.3.3 Future Research Regarding Adaptive Capacity

As a basis for future research leading to development investment, the authors prioritize the institutions according to the following criteria:

1. Information available on the internet regarding adaptive capacity data, and
2. Apparent ability to absorb development support.

Available internet information results in the ranking presented in Table 12, which reflects the finding that the strongest case can be made for LCBC, followed by VBA. OMVG, NBA, and OMVS are the institutions for which the least amount of information is available on the web to make a strong argument on their behalf. OMVG ranked the lowest in terms of capacity, due largely to an absence of information. Very little is known about this organization, other than that it is funded by the ADB to execute a large-scale hydroelectric power project, which includes the construction of two dams and a t-line. Future research on this institution would benefit from a visit not only to the organization’s headquarters to speak with leaders and staff about the adaptive capacity of the organization, but also to various river basin-dependent communities in an effort to understand their needs and expectations for OMVG in the face of climate change. Furthermore, given the almost sheer lack of information on this institution, a field study of this TRBMI would help reveal its ability to respond positively to development investment.

TABLE 12. TRBMI RANKINGS

Ranking (1 = strongest internet presence regarding capacity)	Transboundary River Basin Management Institution
1	LCBC
2	VBA
3	NBA, OMVS
4	OMVG

OMVS and NBA both received the second lowest ranking. These institutions exude the potential to develop their adaptive capacities, but for different reasons have been unable to harness that full potential until now. For example, both have demonstrated an ability to collaborate with donors and technical partners but appear to lack sufficient financial and human resources. In terms of leadership, NBA scored the highest in light of its collaborative efforts and vision for sustainability. The administration of OMVS, which ranked third for this dimension, appears to be improving since the nomination of the new High Commissioner Komara of Guinea.

6.3.4 TRBs and TRBMIs Prioritized for Future Research

In analyzing the results of the three selection criteria — climate vulnerability, economic vulnerability, and need for improved adaptive capacity — the authors suggest that the Niger River Basin is of chief priority for future research. This suggestion takes into consideration the basin’s high level of vulnerability to climate change (most notably in the western basin), its high population and spatial extent, and the limited information available demonstrating that the TRBMI has a strong adaptive capacity. Of secondary priority for research are the Senegal and Gambia River Basins, which rank very high in terms of vulnerability to climate change, in terms of *underutilized* economic potential and the relatively limited information available describing strengths in the adaptive capacity of their TRBMIs.

These three TRBs — the Gambia, Senegal, and Niger Basins — all find their source in the Fouta Djallon highlands of Guinea, known regionally as the “water tower” of West Africa. The Fouta Djallon is also the source of numerous other basins in the region. This presents an opportunity for research to explore the extent to which these institutions are able to work together to manage transboundary hydrologic and ecological resources, and how climate, ecology, and human activities upstream influence water supply and livelihoods downstream.

6.3.5 Donor Investment Opportunities

Development organizations have the unique opportunity to assist West African TRBMs to thrive in the midst of climate change by enhancing their capacity in the following areas.

Collaborate with fellow TRBMs to adaptively co-manage TRBs

There is a clear need for increased collaboration between TRBMs in improving the management of TRBs, especially given the common source of many of these basins in the highlands of Guinea. These institutions can share with one another their lessons learned and best practices for improving sustainable agricultural and fishing livelihoods, hydropower generation, irrigation, conflict resolution, and water resource conservation and allocation. Moreover, such an effort could spur synergy in negotiating treaties and informal agreements between upstream and downstream users. One example of such an effort would be to host a workshop in which officials and technicians would discuss how climatic, ecological, and socioeconomic processes at the source of the rivers in Guinea are influencing water resource availability and access in their respective basins. To date, no such initiative is known to have been supported in West Africa.

Respond to the dynamic needs of local river-dependent populations

Results of the initial adaptive capacity assessment (see Chapter 5) reveal what appears to be a lack of interaction between TRBMs and their river-dependent populations – in spite of clear mandates about the necessity of this interaction. Such an exercise could bring together representatives from institutions and local communities to discuss each of their priorities in developing river basins. The parties may also brainstorm how proposed activities, such as large-scale irrigation, can be harmonized for the benefit of all while minimizing drawbacks especially for small-scale producers, who tend to weather the negative unintended consequences of large-scale projects like dam construction and hydropower generation.

Predict, monitor, and respond to climate variability and extreme events

Most of the TRBMs need improved tools, methods, analysis, and channels of dissemination for collecting and reporting climate and hydrologic data. No evidence was found to describe any climate services they provide to decision-makers and river-dependent populations. There is a need for improved early warning and monitoring systems for drought and flooding, as well as clear plans of action for responding to such events.

Address root causes of anthropogenic water stress

In addition to climate, a host of other biophysical processes — many of which are related to land use/land cover change — determine the water supply in TRBs. Recent research, especially in the Sahel, has exposed the role of human activities like land degradation and deforestation in altering runoff, aquifer recharge, and river discharge levels. TRBMs can take a leading role in combating this trend by offering viable alternatives to such activities while also facilitating traditional, low-input land restoration and reforestation projects. Furthermore, simple methods such as the construction of earthen canals and dykes for small-scale irrigation can also increase efficiency in water use for agriculture.

7.0 ANNEXES

ANNEX A: PROPOSED RESEARCH PLAN

A.1 Questions for Further Research

The following research questions correspond to the gaps in knowledge identified in this desk study, as well as the anticipated information needs of development organizations in pursuing opportunities for investment in West African TRBs and their management institutions. The tables present these questions following the sequence in which the topics they address appear in the study:

- Climate, land use/land cover change, and water supply;
- Upstream-downstream dynamics of water use and supply;
- Climate change decision-making; and
- Adaptive capacity of TRBMs.

The tables further group the questions following the three stages of research options proposed in section 2 of this annex, where they are described in full. Briefly, the phases are: Phase 1, the collection of Foundational Information from key informants; Phase 2, a Regional Workshop of potential partners and stakeholders; and, Phase 3, Primary Data Collection through fieldwork at national, regional, and local levels.

TABLE A.I. CLIMATE, LAND USE/LAND COVER CHANGE, AND WATER SUPPLY

Research questions that merit further exploration	Options and methods to find answers
<p>How do authorities and experts understand the following?</p> <ul style="list-style-type: none"> • Correlations between land use/land cover change, runoff, river basin discharge, and groundwater recharge levels • Impacts of mining on TRBs • Pastoral migration to and through river basins and its effects on water quality and supply • Impacts of extreme climate events (e.g., flooding and drought) on TRB hydroecology • Relations between intense rainfall events, flooding, and water quality • Links between fire and water supply (in consideration of the relationship between vegetation loss and increases in runoff) <p>What actions are being undertaken, if any, to mitigate the negative impacts of the above?</p>	<p>Phase I: Foundations</p> <ul style="list-style-type: none"> • Interviews with TRBMs • Interviews with national-level river basin water resource managers • Interviews with TRB scientific experts and funding agencies. • Review of data and documents (e.g., reports, field notes, meeting minutes) that institutions and experts provide on site <p>Phase II: Regional Workshop with user groups, TRBMs, national managers, funding organizations, donors, etc.</p>

TABLE A.2. UPSTREAM-DOWNSTREAM DYNAMICS OF WATER USE AND SUPPLY

Research questions that merit further exploration	Options and methods to find answers
<p>How do land use/land cover change and resource use at TRB sources influence water quality and supply, resource use, and livelihood activities downstream?</p> <p>How do land use/land cover change and resource use in other upstream riparian areas influence water quality and supply, resource use, and livelihood activities downstream?</p> <p>How do upstream land use/land cover change and resource use influence dam operations downstream?</p> <p>How, if at all, do TRBMs gather, interpret, and use information about upstream/downstream feedbacks?</p> <p>How, if at all, do TRBMs coordinate upstream/downstream river basin management, including the allocation and use of land, water, and natural resources, at the sub-national, national, and international levels?</p> <p>What challenges do civil society, governments, and TRBMs face in upstream/downstream river management; how do they seek to overcome them; and what unmet opportunities exist for their resolution?</p>	<p>Phase I: Foundations</p> <ul style="list-style-type: none"> • Interviews with TRBMs • Interviews with national-level river basin water resource managers • Interviews with TRB scientific experts and funding agencies • Review of data and documents (e.g., reports, field notes, meeting minutes) that institutions and experts provide on-site <p>Phase II: Regional Workshop with user groups, TRBMs, national managers, funding organizations, donors, etc.</p>

TABLE A.3. CLIMATE CHANGE VULNERABILITY, DECISION-MAKING, AND RESPONSE

Research questions that merit further exploration	Options and methods to find answers
<p><i>1. Climate information: access, interpretation, dissemination and use</i></p> <p>How do TRB users, managers, and authorities:</p> <ul style="list-style-type: none"> gain access to information about the impacts of climate variability and change on TRBs; interpret information related to climate and TRBs (including feedbacks between land use/land cover change, water use, and local climate); share information related to climate and TRBs, and with whom; and respond to this information? 	<p>Phase II: Regional Workshop with user groups, TRBMs, national managers, funding organizations, donors, etc.</p> <p>Phase III: Primary Data Collection</p> <p>User Vulnerability and Needs Assessment: Interviews/surveys of government authorities, TRB-dependent populations, and other TRB stakeholders (donors, NGOs, private sector, etc.)</p> <p>Adaptive Capacity Institutional Assessment: Key informant interviews with TRBMs</p>
<p><i>1. Vulnerability</i></p> <p>How do TRB users, managers, and authorities conceptualize, assess, and address vulnerability to climate change in terms of its impacts on TRBs and their dependent populations?</p>	
<p><i>2. Adaptation and coping</i></p> <p>What adaptation and coping mechanisms are river-dependent populations undertaking?</p> <p>Besides climate, which other factors, if any, prompt these populations to adopt adaptation and coping mechanisms?</p> <p>What are the benefits and disadvantages of each of these measures?</p> <p>What are the impacts of these measures on TRBs (water quality, supply, hydroecology, etc.)?</p>	
<p><i>3. Mitigation</i></p> <p>What measures, if any, are being taken locally to mitigate climate change in TRBs, and by whom?</p>	

TABLE A.4. TRBMI OPERATIONS, ADAPTIVE CAPACITY, AND OPPORTUNITIES FOR IMPROVEMENT

Research questions that merit further exploration	Options and methods to find answers
<p>1. <i>Hardware</i></p> <p>What hardware (physical infrastructure, equipment, tools, etc.) do TRBMIs use to manage their basins?</p> <p>What other types of hardware may help strengthen the adaptive capacity of TRBMIs and their constituent populations, and what are the advantages and disadvantages — and for whom — of using this hardware?</p>	<p>Phase I: Foundations</p> <ul style="list-style-type: none"> • Interviews with TRBMIs • Interviews with national-level river basin water resource managers • Interviews with TRB funding agencies. • Review of data and documents (e.g., reports, field notes, meeting minutes) that institutions and experts provide on-site <p>Phase III: Primary Data Collection</p> <p>User Vulnerability and Needs Assessment: Interviews/surveys of government authorities, TRB-dependent populations, and other TRB stakeholders (donors, NGOs, private sector, etc.)</p> <p>Adaptive Capacity Institutional Assessment: Key informant interviews with TRBMIs</p>
<p>2. <i>Programming</i></p> <p>What programs have TRBMIs implemented, or will they implement in the future?</p> <p>Have TRBMIs undertaken any navigation programs?</p> <p>What have been the challenges, outcomes, impacts, and learning experiences associated with TRBMI programs?</p> <p>Have TRBMIs implemented any programs to address key documented challenges like invasive species and ecological and water supply problems related to dam operations?</p> <p>How can TRBMIs improve their management of TRBs, and how can partners (such as USAID) assist them in doing so?</p>	
<p>3. <i>Psychological capacity and institutional self-awareness</i></p> <p>How do TRBMIs conceptualize adaptive capacity?</p> <p>How do they estimate their own capacity levels? Are formal systems in place for self-evaluation?</p> <p>Do TRBMIs recognize a need to improve their adaptive capacity? What could be done to do so?</p>	<p>Phase III: Primary Data Collection</p> <p>Adaptive Capacity Institutional Assessment: Key informant interviews with TRBMIs</p>
<p>4. <i>Institutional memory and learning</i></p> <p>How do TRBMIs learn from their organizational, operational, and programmatic experiences? How do lessons learned inform decision-making and future work, if at all?</p> <p>Do TRBMIs keep consistent records of their operations? Can staff readily access these records?</p>	

Research questions that merit further exploration	Options and methods to find answers
<p>Are systems for self-evaluation or internal auditing in place to structure the learning process? If so, what have been the results of these evaluations and how have they been used to inform decision-making, if at all?</p> <p>What tools and processes are used to assess TRB issues and monitor, evaluate, and report the outcomes of TRBMI initiatives?</p>	
<p>5. <i>Leadership and governance</i></p> <p>How do TRBMI leaders rank in terms of competency, taking into consideration educational background, skill sets, and professional experience?</p> <p>How are TRBMI leadership teams structured, and how are executive powers distributed through these structures?</p> <p>How do leaders and institutions as a whole rank in terms of transparent and just governance?</p> <p>How well have TRBMIs fulfilled their respective mandates and constitutions?</p>	
<p>6. <i>Collaboration</i></p> <p>With whom have TRBMIs collaborated in managing TRBs (including organizations, institutes, donors, and other TRBMIs), and what have been the outcomes of these collaborations?</p> <p>What could be done to improve the current and future collaborative partnerships of TRBMIs?</p>	
<p>7. <i>Resources</i></p> <p>How do the <i>human resources</i> of TRBMIs rank in terms of overall competency?</p> <p>How, if at all, do TRBMIs foster the capacity and professional development of their <i>human resources</i>? What more could be done in this capacity?</p> <p>Where do TRBMIs obtain <i>financial resources</i>, and how are these resources managed?</p> <p>Do current <i>financial resources</i> suffice for fulfilling TRBMI objectives?</p> <p>What can be done to improve the consistency and timeliness of member state donations?</p>	

Research questions that merit further exploration	Options and methods to find answers
<p>8. <i>Relations with constituent populations</i></p> <p>How and how often do TRBMs communicate with river-dependent populations about the latter's needs?</p> <p>How much do populations depend on TRBMs to fulfill their needs?</p> <p>How successful have TRBMs been in addressing the prioritized needs of their populations?</p> <p>What can partners (such as USAID) do to improve the relationships between TRBMs and their constituent populations, as well as the responsiveness of the former to the latter's needs?</p>	<p>Phase III: Primary Data Collection</p> <p>User Vulnerability and Needs Assessment: Interviews/surveys of government authorities, TRB-dependent populations, and other TRB stakeholders (donors, NGOs, private sector, etc.)</p>

A.2 Research Options

The proposed research is designed to address both the adaptive capacity of TRB/MIs and the biophysical, socioeconomic, and geopolitical dynamics shaping vulnerability to climate change in the river basins in which they have authority. This approach is discussed in more detail in Section 1.2 of this report. We propose three phases of research.

- Phase 1, **Foundational Information**, uses a literature review of documentation provided on-site as well as structured interviews with key informants on the programs that development organizations, government agencies, and other actors in West African TRBs are currently implementing or planning.
- Phase 2, a **Regional Workshop**, will provide an opportunity for all partners to share lessons learned, brainstorm ideas for future programming, and explore synergies. The results of this initial meeting, combined with those of Phase 1, will help refine the questions and methods used for primary data collection in Phase 3.
- Phase 3, **Primary Data Collection**, will involve the collection of primary data at local, national, and regional levels to fill gaps in knowledge about the function, management, and programmatic needs of TRB/MIs. Using this approach, the authors recommend staging the research as follows:

Phase I: Foundational Information (global interests in the region)

Estimated LOE: 15 days (not including travel) once contacts are established and six to eight meetings are set up.

This phase consists of interviews with TRB managers, experts, and funding organizations of past, current, or planned research and development programs in TRBs. It is designed to 1) fill any gaps in knowledge about TRB dynamics (Tables A1 and A2 of research questions); and 2) answer questions about the results of funded programs, the present adaptive capacity of TRBs and their management institutions, and opportunities for development organizations to invest in strengthening adaptive capacity (select questions from Table A4). Face-to-face interviews would be most efficient, and conveniently, most of the funding organizations listed below have regional offices in Dakar. This component will also draw on any literature interviewees provide on-site.

- TRBMs – Dakar and Niamey
- National-level river basin and water resource managers – capital cities of select riparian countries
- Institut de recherche pour le développement (IRD) (scientific expert on West African TRBs) – Montpellier, France/Dakar
- Funding organizations:
 - GTZ – Bonn, Germany/Dakar)
 - World Bank – D.C./Dakar/Accra/Conakry
 - ADB - Tunis/Dakar
 - CIDA – Ottawa/Niamey

Phase II: West African Transboundary River Basin Workshop in Dakar

Estimated LOE (not including travel): 15 days for three WAVA team members to prepare, schedule, and run the workshop with a local facilitator

The proposed workshop would provide an opportunity for all partners — user groups, managers, scientists, technicians, and especially the TRBMs to share their knowledge of TRBs vis-à-vis climate change; exchange experiences, lessons, and priorities of TRB use and management; collectively brainstorm ideas for improving TRB use and management; and explore synergies in adaptive co-management across basins. This two-day workshop is meant to address Tables A1, A2, and A3 of the proposed research questions.

The workshop would consist of presentations by various partners on work to date followed by break-out sessions in which smaller groups would discuss opportunities for future efforts.

Phase III: Primary Data Collection (mixed methods: qualitative and quantitative)

The foundational interviews and regional workshop would lay the groundwork for Phase III. This phase would consist of two components.

1. The first would assess the vulnerability and needs for improving climate change resilience in the riparian countries of targeted TRBMs. It is recommended that research be conducted in at least six riparian countries; this would ensure the study of at least one upstream and two downstream riparian countries for each of the three TRBMs. Such a sampling may include, for example, Guinea (as the source of all three targeted TRBs), The Gambia, Mali, Niger, Nigeria, and Senegal.
2. The second component would assess the institutional adaptive capacity of the TRBMs themselves. It would take place at the headquarters of these institutions (Table A4 and select questions from Table A3). The results of both assessments would inform potential donor programming in TRBs, which may take the form of investment in their management institutions, member states, and/or dependent populations.

I. TRB User Vulnerability and Needs Assessment (UVNA)

Estimated LOE (not including travel): 10 days for each selected country for two team members, plus a medium-sized local team of six to eight local researchers.

This research effort will measure the vulnerability and outstanding needs of TRBMI member states and TRB-dependent populations in terms of improving their resilience to climate change (Table A3 and select questions from Table A4). It will use a purposefully selected sample of (at least) six riparian countries corresponding to (at least) three TRBMIs. In each selected country, UVNA interviews and surveys will be developed to study three groups with different sampling strategies and slightly different questions for each:

- a) Government authorities (decision-makers in ministries or units such as water, energy, agriculture, livestock, fishing, and environment) at multiple levels (central and decentralized)
- b) Other entities working in TRBs (donors, NGOs, private sector)
- c) TRB-dependent populations in three groups: farmers, pastoralists, and fishers

The study of farmers and pastoralists will take place in capital and other major cities, while the study of fishers, some of which will be located in rural areas, will require more travel time.

2. Adaptive Capacity Institutional Assessment

Estimated LOE (not including travel): Five days for each selected country for two team members, plus a small team of three to five local researchers.

This component of the research would evaluate the adaptive capacity of targeted TRBMIs (questions from Table A3 and A4). The literature review and key informant interviews prepared for this component would measure the Gupta Adaptive Capacity Wheel's six dimensions of adaptive capacity (Section 5.1) — *variety, learning capacity, room for autonomous change, resources, fair governance, and leadership* — in addition to two other dimensions deemed integral to improving adaptive capacity: *hardware*, which includes the equipment, technology and infrastructure required to build capacity, as well as *psychological capacity*, or the personal or institutional belief that one can, wants to, and should adapt to climate change (Grothmann et al., 2013.)

The majority of this assessment would take place in capital cities, requiring a smaller team and less time than the UVNA component.

TABLE A.5. PHASE III

	Phase I: Foundations	Phase II: Workshop	Phase III: Primary Data Collection	
			TRB User Vulnerability and Needs Assessment (UVNA)	Adaptive Capacity Institutional Assessment
Level of Effort	15 days per person	15 days per person	10 days per person/country	Five days per person/country
Human Resources	Two team members	Three team members One African facilitator	Two team members; plus medium-sized local team (six to eight people)	Two team members plus small local team (three to five people)
Duration from preparation to final deliverable	Three weeks in early Fall 2013	Three weeks in mid Fall 2013	Four to five months; could be halved if trained national teams could work simultaneously	Two months, adequate national teams could allow this to be run simultaneously with UVNA; see left
Proposed siting /sampling	D.C., Dakar, Niamey	Dakar	Six countries (TBD)	Dakar and Niamey

ANNEX B: AVAILABLE MAPPING RESOURCES FOR WEST AFRICAN TRANSBOUNDARY RIVER BASINS

The following table lists the most recent mapping products of West African TRBs and their relevant features according to their year of creation, beginning with the most recent.

TABLE B.1. MAPPING RESOURCES

Source	Mapping Products	Year of creation
Water and Global Change http://www.waterandclimatechange.eu/land-cover/niger-land-cover	<ul style="list-style-type: none"> • Niger River Basin evaporation in average year • Niger River Basin land in average year • Niger River Basin elevation gradients • Niger River Basin land cover types 	2013
The Food and Agriculture Organization (FAO) http://www.fao.org/docrep/017/i3037e/i3037e.pdf	<ul style="list-style-type: none"> • Lake Chad Basin and its riparian countries • Main attributes in the Lake Chad Basin 	2011
Descroix, L.; Mahé, G; Lebel, T.; Favreau, G.; Galle, S.; Gautier, E.; Olivry, J.-C.; Albergel, J.; Amoga, O.; Cappelaere, B.; Dessouassi, R.; Diedhiou, A.; Le Breton, E.; Mamadou, I.; Sighomnou, D. http://ccsl.iccip.net/niger_river_basin.pdf	<ul style="list-style-type: none"> • Niger River Basin and the four sub-basins 	2009
International Union for Conservation of Nature and Natural Resources (IUCN) http://cmsdata.iucn.org/downloads/t	<ul style="list-style-type: none"> • West African ecological regions • Major watersheds in West Africa: River basins as delineated by Hydro1K²⁰ and as used to map and analyze species distribution 	2009

²⁰ The USGS website at <https://ita.cr.usgs.gov/HYDRO1K> states that “HYDRO1K is a geographic database developed to provide comprehensive and consistent global coverage of topographically derived data sets, including streams, drainage basins and ancillary layers derived from the USGS’ 30 arc-second digital elevation model of the world (GTOPO30).”

Source	Mapping Products	Year of creation
he_status_and_distribution_of_freshwater_biodiversity_in_western_africa.pdf	<ul style="list-style-type: none"> • Distribution of freshwater fish species in West Africa; species richness = the number of species present in each 289 km² hexagonal grid • The distribution of freshwater fish species endemic to western Africa; species richness = the number of species present in each 289 km² hexagonal grid • The distribution of threatened freshwater fish species in western Africa; species richness = the number of species present in each 289 km² hexagonal grid • Freshwater mollusk species richness in the western Africa region; species richness = species per hexagonal grid cell (289 km²) • Endemic freshwater mollusk species richness in the western Africa region; species richness = species per hexagonal grid cell (289 km²) • Freshwater crab species richness in western Africa; species richness = species per hexagonal grid cell (289 km²) • Threatened freshwater crab species richness in western Africa; species richness = species per hexagonal grid cell (289 km²) 	
Global Change and the Hydrological Cycle (GLOWA) http://www.glowa-volta.de/publ_maps.html	<ul style="list-style-type: none"> • Location of the Volta Basin on the African Continent and its riparian countries • Spatial distribution of population density in the Volta River Basin • Main land cover types in the Volta River Basin • Digital Elevation Model showing elevation gradients across the Volta River Basin • Domestic water consumption in the Volta River Basin 	2008

HYDRO1k provides a suite of geo-referenced data sets, both raster and vector, which will be of value for all users who need to organize, evaluate, or process hydrologic information on a continental scale.”

Source	Mapping Products	Year of creation
UNEP http://www.unep.org/dewa/africa/africaAtlas/PDF/en/Africa_Atlas_Full_en.pdf	<ul style="list-style-type: none"> Major river and groundwater basins of West Africa 	2008
Pan African Congress of Mathematicians (PACOM) http://start.org/download/gec07/dia-final.pdf	<ul style="list-style-type: none"> Senegal River basin elevation map showing elevation gradients Flow direction in the Senegal River Basin Flow length of the Senegal River Basin Slope of the Senegal River Basin Sub-basins of the Senegal River Basin Travel time and velocity in the Senegal River Basin Spatial distribution of soil moisture in the Senegal River Basin 	2007
International Centre for Livestock Research and Development in Sub-Humid Zones http://www.westafricagateway.org/west-africa/region	<ul style="list-style-type: none"> Transboundary water basins in West Africa in location to one another Spatial distribution of renewable water across West Africa Soil suitability for agriculture in West Africa 	2006
FAO http://www.zef.de/fileadmin/webfiles/downloads/zef_wp/wp100.pdf	<ul style="list-style-type: none"> Soil associations with dominant soil groups across Western Africa 	2003
Hamerlynck, O. and Duvail, S http://data.iucn.org/dbtw-wpd/edocs/WTL-029.pdf	<ul style="list-style-type: none"> Senegal River Basin and the locations of the Diama and Manantali dams 	2003
Commision du Bassin du Lac Tchad http://www.cbtl.org/fr/lac-tchad	<ul style="list-style-type: none"> Major land use and land cover types in the Chad River Basin 	2001
USGS http://lca.usgs.gov/lca/africalulc/results.php	<ul style="list-style-type: none"> Land use and land cover change in West Africa 	2000

Source	Mapping Products	Year of creation
International Union for Conservation of Nature and Natural Resources (IUCN) http://cmsdata.iucn.org/img/original/gambia_river_catchment.jpg	<ul style="list-style-type: none"> Map of the Gambia River Basin and its riparian countries 	n.d.
World Wildlife Fund http://awsassets.panda.org/downloads/mrwlakechadcasestudy.pdf	<ul style="list-style-type: none"> Map of Lake Chad and its riparian countries 	n.d.

BI. Mapping needs

On the following page, the authors identified two currently unavailable mapping products that, if developed, would support the research and programmatic decision-making of donors and their partners in West African TRBs.

1. West African TRBMs are more in need of automated mapping systems than maps, which are already available (except for land use/land cover change maps; please see item 2 below). Such a system would allow for daily, weekly, or bi-weekly monitoring of TRBs via variables such as climate, flooding, fire, drought, water levels (both surface and groundwater), agricultural production, etc. This system would automatically collect and process different remote sensing data (Vegetation Index, climate data, etc.) from various sensors at different spatial and temporal resolutions via a National Aeronautics and Space Administration (NASA) or similar server. The system would then automatically generate maps at regular intervals. In the short term, CIESEN (or whichever entity is contracted to build this system) could train TRBMI technicians to interpret the maps and use them to TRB management. In the long-term, TRBMs could take over the system themselves, as all that is needed to run it is a single server and computer. The authors believe that this automated system would enable TRBMs to build their adaptive capacities by improving real-time monitoring, early warning, and response at little to no cost.
2. There is an urgent need to create new land use/land cover change maps for TRBs at a lower spatial resolution, either 10 meters (Spot) or 30 meters (Landsat). The current maps are outdated and have much lower resolutions.

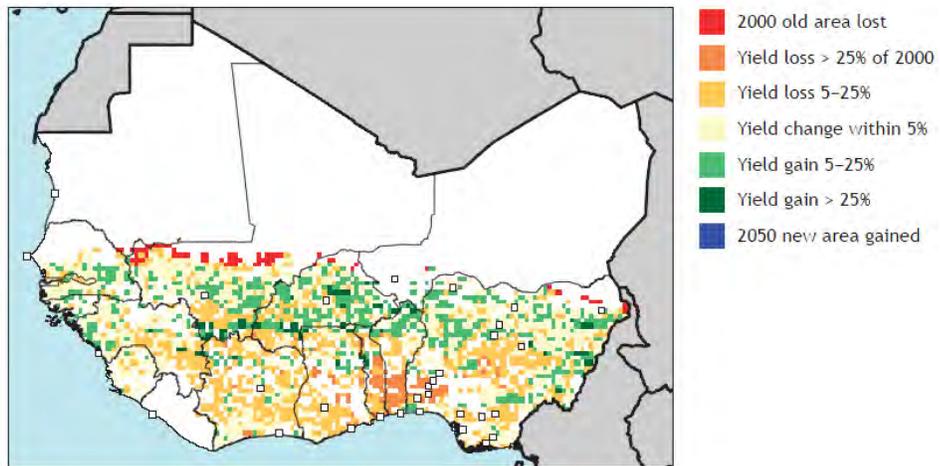
ANNEX C: IMPACTS OF CLIMATE CHANGE ON AGRICULTURAL PRODUCTION

It is a well-founded and well-documented hypothesis that climate change has and will continue to menace agricultural production, farm incomes, and welfare in West Africa (2013). In Burkina Faso, for example, cotton, maize, and yam production are dwindling due to drought impacts, and projected rainfall decreases (3.4 percent by 2025 and by 7.3 percent by 2050) are expected to reproduce this pattern in the future. In Ghana, maize yields are projected to decrease by 7 percent as a result of climate change-induced extreme weather events (Brown & Crawford, 2008). Furthermore, in the Niger River Basin, drying of summer surface and root soil under future climate change is expected to reduce rain-fed food production; likewise, farmers relying on river water are vulnerable to future reductions in peak rainfall and hence surface runoff (Oguntunde & Abiodun, 2013).

Other shifts in agriculture resulting from ongoing climate change include shifts in the length of growing season due to false starts and rain cessation (IPCC, 2008a). In addition, Jalloh et al. (2013) predict that temperature spikes will cause a decline in crop yields and increase weed and pest propagation; furthermore, precipitation variability will increase crop susceptibility to short-term failures and decrease long-term production. These trends, they note, will be particularly severe in the Sahel.

The above prognoses are for the region as a whole. On the sub-regional level, however, there is considerable geographic disparity in predicted food production levels. The below study forecasts changes in maize yields throughout West Africa between 2000 and 2050 (see figure below). Along the southern coast of the region, yields are predicted to decrease by 5 to 25 percent, while a 5 to 25 percent gain is expected in many areas of the Sahel. These estimates appear to be fairly commensurate with the rainfall projections for the region, which forecast greater precipitation in the central and eastern Sahel with less in the southern zones (Jalloh et al., 2013).

FIGURE C.1. CHANGES IN MAIZE YIELDS (PERCENT) FROM 2000 TO 2050 FROM THE DSSAT CROP MODEL, SCENARIO A1B



Source: Jalloh et al., 2013

8.0 REFERENCES

- Abutu, A. (2013). Nigeria: Lake Chad Basin Commission discusses modalities to recharge the Lake. Retrieved from <http://allafrica.com/stories/201305020448.html>
- ActionAid. (2006). Climate change, urban flooding and the rights of the urban poor in Africa Key findings from six African cities. Retrieved from ipcc-wg2.gov/njlite_download.php?id=6816
- Adano, W. R., Dietz, T., Witsenburg, K., and Zaal, F. (2012). Climate change, violent conflict and local institutions in Kenya's drylands. *Journal of Peace Research* 49(1), 65-80.
- African Development Bank Group. (2013). Briefing Notes for AfDB's Long-Term Strategy. Briefing Note 4: Africa's Demographic Trends. Retrieved from <http://www.afdb.org/fileadmin/uploads/afdb/Documents/Policy-Documents/FINAL%20Briefing%20Note%204%20Africas%20Demographic%20Trends.pdf>
- African Network of Basin Organizations (ANBO). (2007). The Sourcebook on Africa's River Basin Organizations (RBO) volume I.
- African Online News (AON). (2007). Gambia River Basin hydroelectric project to start. Retrieved from <http://www.afrol.com/articles/15396>
- All Africa. (2013). Kenya: Mobile Phones Boosting Innovation in Livestock Sector - UN Agency. Retrieved from <http://allafrica.com/stories/201303011280.html>
- Amani, A., and Nguetora, M. (2002). Evidence d'une modification du regime hydrologique du fleuve Niger a Niamey. *Iahs Publication*, 274, 449-456.
- Andersen, I., and Golitzen, K. G. (Eds.) (2005). The Niger River basin: A vision for sustainable management. World Bank.
- Ardoin-Bardin, S., Servat, E., and Universite des sciences et techniques de Montpellier 2. (2004). Variabilite hydroclimatique et impacts sur les ressources en eau des grands bassins hydrographiques en zone soudano-sahelienne." S.l.: s.n.
- Arnell, N. W. and Gosling, S. N. (2013). The impacts of climate change on river flow regimes at the global scale. *Journal of Hydrology*, 486, 351-364. ISSN 0022-1694. doi: 10.1016/j.jhydrol.2013.02.010
- Autorité du bassin du Niger (n.d). Major studies. Retrieved from http://www.abn.ne/index.php?option=com_content&view=category&layout=blog&id=14&Itemid=10&lang=en
- Autorité du Bassin du Niger (ABN). (2011a). "Good cooperation among basin organizations: NBA and OMVS. Retrieved from http://www.abn.ne/index.php?option=com_content&view=article&id=78%3A1a-bonne-cooperation-entre-organismes-de-bassin-abn-a-omvs&catid=38%3AAnouvelles&Itemid=34&lang=en

- Autorité du Bassin du Niger (ABN). (2011b). Les principes de gestion et de bonne gouvernance pour un développement durable et partagé du Bassin du Niger. Retrieved from http://www.abn.ne/index.php?option=com_content&view=category&layout=blog&id=25&Itemid=22&lang=en
- Autorité du Bassin du Niger (ABN). (2012). 10th Summit of the Heads of State and Government, N'Djamena from 6th to 11th May, 2013. Retrieved from <http://www.abn.ne/>
- Autorité du Bassin du Niger (ABN). (2012a). Programme de Renforcement des Capacités (PRC/ACDI). Retrieved from http://www.abn.ne/index.php?option=com_content&view=category&layout=blog&id=20&Itemid=20&lang=en
- Autorité du Bassin du Niger (ABN). (2012b). The opening ceremony of a Regional Workshop for Validating the Draft Report of NBA's Strategic Plan and the Regional Steering Committee for Projects and Programmes of NBA. Retrieved from http://www.abn.ne/index.php?option=com_content&view=article&id=131%3Aouverture-de-latelier-de-validation-du-rapport-provisoire-du-plan-strategique-et-du-comite-regional-de-pilotage-des-projets-et-programmes-de-labn&catid=38%3Anouvelles&Itemid=34&lang=en
- Autorité du Bassin du Niger (ABN). (2012c). Règlement Intérieur de la Coordination Camerounaise du Bassin du Niger (CCUBN). Retrieved from http://www.abn.ne/index.php?option=com_content&view=category&layout=blog&id=55&Itemid=48&lang=en
- Badjeck, M. C., Katikiro, R. E., Flitner, M., Diop, N., and Schwerdtner Máñez, K. (2011). Workshop on Envisioning 2050: climate change, aquaculture and fisheries in West Africa', Dakar, Senegal, 14-16 April 2010. In Workshop on Envisioning 2050: climate change, aquaculture and fisheries in West Africa', Dakar, Senegal, 14-16 April 2010. WorldFish Center.
- Bakker, M. H. (2007). Transboundary river floods: vulnerability of continents, international river basins and countries. Retrieved from http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/3821/Dissertation_complete_signed_16Jan07.pdf?sequence=1
- Bakker, M. H. (2009). Transboundary River Floods and Institutional Capacity. *JAWRA Journal of the American Water Resources Association*, 45(3), 553-566.
- Barnett, J., and Adger, W. N. (2007). Climate change, human security and violent conflict. *Political Geography*, 26(6), 639-655.
- Below, T., Artner, A., Siebert, R., and Sieber, S. (2010). Micro-level practices to adapt to climate change for African small-scale farmers. A Review of Selected Literature. Environment and Production Technology Division.
- Benjaminsen, T. A. (2008). Does supply-induced scarcity drive violent conflicts in the African Sahel? The case of the Tuareg rebellion in northern Mali. *Journal of Peace Research*, 45(6), 819-836.
- Biggs, R., E. Bohensky, P.V. Desanker, C. Fabricius, T. Lynam, A.A. Misselhorn, C. Musvoto, M. Mutale and Co-authors. (2004). Nature Supporting People: The Southern African Millennium Ecosystem Assessment Integrated Report. Millennium Ecosystem Assessment, Council for Scientific and Industrial Research, Pretoria, 68 pp.

- Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo and P. Yanda. (2007). Africa. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (Eds.). Cambridge UK: Cambridge University Press, 433-467.
- Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo and P. Yanda. (2007). Africa: Climate Change Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson (Eds.). Cambridge UK: Cambridge University Press, 433-467.
- Brockhaus, M., Djoudi, H., and Locatelli, B. (2013). Envisioning the future and learning from the past: Adapting to a changing environment in northern Mali. *Environmental Science and Policy*, 25, 94-106.
- Brown, O., and Crawford, A. (2008). Assessing the security implications of climate change for West Africa: country case studies of Ghana and Burkina Faso.
- Brugère, C. (2006). A review of the development of integrated irrigation aquaculture (IIA), with special reference to West Africa. Integrated irrigation and aquaculture in West Africa: concepts, practices and potential (27-60).
- Butler, C. K. and Gates, S. (2012). African range wars: Climate, conflict, and property rights. *Journal of Peace Research*, 49(1), 23-34.
- Cappelaere, et al. (2009). The AMMA catch observing system in the cultivated Sahelian of South West Niger – strategy, implementation and site conditions. *Journal of Hydrology* 375 (1–2), 34–51.
- Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (Eds.)]. Cambridge, UK, and New York, NY, USA: Cambridge University Press, 582 pp.
- Chappell, A., and Agnew, C. T. (2004). Modelling climate change in West African Sahel rainfall (1931–90) as an artifact of changing station locations. *International Journal of Climatology*, 24(5), 547-554
- Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, R., ... and Dethloff, K. (2007). Regional climate projections. Climate Change, 2007: The Physical Science Basis. Contribution of Working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, University Press, Cambridge, Chapter 11, 847-940.
- CIFOR. (2005). Natural Resources, Communities and Climate Change in West Africa: Impacts, Vulnerabilities and Responses. Center for International Forestry Research, Ouagadougou.
- Conway, D. (2000). "The climate and hydrology of the Upper Blue Nile River." *Geogr. J.*, 166, 49–62.
- Conway, D., Persechino, A., Ardoin-Bardin, S., Hamandawana, H., Dieulin, C., and Mahae, G. (2009). Rainfall and Water Resources Variability in Sub-Saharan Africa during the Twentieth Century. *Journal of Hydrometeorology*, 10(1), 41-59.
- Dai, A., Lamb, P. J., Trenberth, K. E., Hulme, M., Jones, P. D., and Xie, P. (2004). The recent Sahel drought is real. *International Journal of Climatology*, 24(11), 1323-1331.

- Daily Observer Forward with the Gambia. (2008). Gambia River Basin states meet on energy needs. Retrieved from <http://observer.gm/africa/gambia/article/2008/5/28/gambia-river-basin-states-meet-on-energy-needs>
- De Stefano, L., Duncan, J., Dinar, S., Stahl, K., Strzepek, K., and Wolf, A. (2010). Mapping the resilience of international river basins to future climate change-induced water variability. World Bank Water Sector Board Discussion Paper Series, 15.
- de, W. M., and Stankiewicz, J. (2006). Changes in Surface Water Supply across Africa with Predicted Climate Change. *Science*, 311(5769), 1917-1921
- Denton, F., Sokona, Y., and Thomas, J. P. (2000). Climate change and sustainable development strategies in the making: what should West African countries expect? *Environnement et Développement du Tiers Monde (ENDA-TM)*.
- Descroix, L., Mahé, G., Lebel, T., Favreau, G., Galle, S., Gautier, E., ... and Sighomnou, D. (2009). Spatio-temporal variability of hydrological regimes around the boundaries between Sahelian and Sudanian areas of West Africa: A synthesis. *Journal of Hydrology*, 375(1), 90-102.
- Dezetter, A., Girard, S., Paturel, J.E., Mahe, G, Ardoin-Bardin, S., and Servat. E. (2008) Runoff simulation in West Africa: implementation of a spatialized monthly modelling process. *J. Hydrol.* 354, 203-212.
- Dickson, K. B. and Benneh, G. (2001). A new geography of Ghana. Longman Group UK Limited. Longman House, Burnt Mill, Harlow, Essex, England.
- Elbersen, W. (2005). Typha for Bioenergy. Retrieved from <http://www.probos.net/biomassa-upstream/pdf/reportBUSBI.pdf>
- Environmental Protection Agency (EPA). (n.d.). International impacts and adaptation. Retrieved from <http://www.epa.gov/climatechange/impacts-adaptation/international.html>
- European Commission (EC). (2012). Aide d'urgence aux 95.000 victimes des inondations en Afrique de l'Ouest. Retrieved from http://ec.europa.eu/echo/files/aid/countries/20121026_IP.pdf
- Feed the Future. (2011). West Africa FY 2011–2015 multi-year strategy. Retrieved from <http://www.feedthefuture.gov/sites/default/files/country/strategies/files/WestAfricaRegionalFTFMulti-YearStrategy.pdf>
- Field, C.D. (1995). Impact of Impact of expected climate change on mangroves. *Asia-Pacific Symposium on Mangrove Ecosystems* (75-81).
- Food and Agricultural Organization (FAO). (1995). Strategies for Water Hyacinth Control. Retrieved from http://www.fao.org/fileadmin/templates/agphome/documents/Biodiversity-pollination/Weeds/Docs/Water_Hyacinth.pdf
- Food and Agricultural Organization (FAO). (2007). Irrigation potential in Africa: A basin approach. Retrieved from <http://www.fao.org/docrep/W4347E/W4347E00.htm>
- Food and Agricultural Organization (FAO). (2008). Building adaptive capacity to climate change. Retrieved from <http://www.fao.org/docrep/010/a1115e/a1115e00.pdf>
- France24. (2013). Climate change to hit Volta Basin for energy, farming. Retrieved from <https://docs.google.com/document/d/1mfTN3FkpfNpjQL2cE6EKGvGh3JEI-n2z0PFzFJC53YU/edit>

- Gambia River Basin Development Organisation (OMVG). (n.d.). Energy project environmental and social impact assessment summary. Retrieved from <http://www.afdb.org/fileadmin/uploads/afdb/Documents/Environmental-and-Social-Assessments/30744628-EN-OMVG-ENERGY-ESIA-SUMMARY.PDF>
- Garrison, J.L. (2010). Report to USAID West Africa: Opportunities and Recommendations for the Design of a New Regional Climate Change Adaptation Program.
- Giannini, A., Saravanan, R., and Chang, P. (2003). Oceanic forcing of Sahel rainfall on interannual to interdecadal time scales. *Science*, 302(5647), 1027-30.
- Giannini, A., Biasutti M., and Verstraete M.M. (2008). A climate model-based review of drought in the sahel: Desertification, the re-greening and climate change. *Global Planet. Change Global and Planetary Change*, 64(3-4), 119-128.
- Gilles van Kote. (2012). Les conséquences des inondations en Afrique de l'Ouest aggravées par l'homme. Retrieved from http://www.lemonde.fr/planete/article/2012/09/19/les-consequences-des-inondations-en-afrique-de-l-ouest-aggravees-par-l-homme_1762306_3244.html
- Gilman, E. L., Ellison, J., Duke, N. C., and Field, C. (2008). Threats to mangroves from climate change and adaptation options: a review. *Aquatic Botany*, 89(2), 237-250.
- Global Change and Hydrological Cycle in the Volta Basin (GLOWA Volta). (2010). Sustainable Development of Research Capacity in West Africa based on the GLOWA Volta Project. Retrieved from <http://www.glowa-volta.de/index.php?id=1639>
- Global International Waters Assessment (GIWA). (n.d.). Causal chain analysis. Retrieved from http://www.unep.org/dewa/giwa/areas/reports/r41/causal_chain_analysis_giwa_r41.pdf
- Gonzalez, P., (2001). Desertification and a shift of forest species in the West African Sahel. *Climate Res.*, 17, 217-228.
- Graefe, S., Sonou, M., and Cofie, O.O. (2006). Informal irrigation in urban West Africa: An overview (Vol. 102). Colombo: International Water Management Institute.
- GRID-Arendal. (2002). Availability of freshwater in Western Africa. Retrieved from <http://www.grida.no/publications/other/aeo/?src=/aeo/166.htm>
- Grothmann T., et al. (2013). Assessing institutional capacities to adapt to climate change—integrating psychological dimensions in the Adaptive Capacity Wheel. *Hazards Earth Syst. Sci. Discuss.*, 1, 793-828.
- Grove, A. T. (1996): African river discharges and lake levels in the twentieth century. *The Limnology, Climatology and Paleoclimatology of the East African Lakes*, T. C Johnson and E. O.
- Gupta, J., Termeer, C., Klostermann, J., Meijerink, S., van den Brink, M., Jong, P., ... and Bergsma, E. (2010). The adaptive capacity wheel: a method to assess the inherent characteristics of institutions to enable the adaptive capacity of society. *Environmental Science and Policy*, 13(6), 459-471.
- Hamandawana, H. (2007): The desiccation of southern Africa's Okavango Delta: Periodic fluctuation or long-term trend? *Past Global Changes*, 15, 12–13.
- Hamouda, M. A., Moursy, F. I., and Nour, E.-D. M. M. (2009). Vulnerability assessment of water resources systems in the Eastern Nile Basin. *Water Resources Management*, 23(13), 2697-2725.

- Hendrix, C. S., and Salehyan, I. (2012). Climate change, rainfall, and social conflict in Africa. *Journal of Peace Research*, 49(1), 35-50.
- Herrmann, S. M., Anyamba, A., and Tucker, C. J. (2005). Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change*, 15(4), 394-404.
- Hewawasam, I., (2002). Managing the marine and coastal environment of sub-Saharan
- Heyder, U., Schaphoff, S., Gerten, D., and Lucht, W. (2011). Risk of severe climate change impact on the terrestrial biosphere. *Environmental Research Letters*, 6(3), 034036.
- Hutchinson, C. F., Herrmann, S. M., Maukonen, T., and Weber, J. (2005). Introduction: The “Greening” of the Sahel. *Journal of Arid Environments*, 63(3), 535-537.
- IIED and SOS Sahel. (n.d.). Securing Pastoralism Summary Sheet. Retrieved from <http://www.sahel.org.uk/documents/SecuringPastoralismsummarysheet.pdf>
- Independent Evaluation Group, World Bank, International Finance Corporation, Multilateral Investment Guarantee Agency. (2010). Responding to floods in West Africa: Lessons from evaluation. Retrieved from http://siteresources.worldbank.org/EXTDIRGEN/Resources/flood_note.pdf
- International Institute for Environment and Development (IIED), SOS Sahel. (2011). Modern and mobile: The future of livestock production in Africa’s drylands. Retrieved from <http://pubs.iied.org/pdfs/12565IIED.pdf>
- International Water Law Project (IWLP). (n.d). Convention relating to the creation of the Gambia River Basin. Retrieved from <http://www.internationalwaterlaw.org/documents/regionaldocs/gambia-river.html>
- IPCC. (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (Eds.)]. IPCC, Geneva, Switzerland, 104 pp.
- IPCC. (2008). Chapter: 5 Analyzing regional aspects of climate change and water resources.
- IPCC. (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate.
- Jalloh, A., Nelson, G., Thomas, T., Zougmore, R. B., and Roy-Macauley, H. (Eds.). (2013). West African agriculture and climate change: A comprehensive analysis. Retrieved from <http://www.ifpri.org/sites/default/files/publications/rr178.pdf>
- Katikiro, R. E., and Macusi, E. D. (2012). Impacts of Climate Change on West African Fisheries and its Implications on Food Production. *Journal of Environmental Science and Management*, 15(2).
- Kiepe, P., and Cotonou, B. (2006). Characterization of three key environments for integrated irrigation-aquaculture and their local names. *Integrated irrigation and aquaculture in West Africa*, 1.
- Labat, D., Godd ris, Y., Probst, J. L., and Guyot, J. L. (2004). Evidence for global runoff increase related to climate warming. *Advances in Water Resources*, 27(6), 631-642.
- Lebel, T., Cappelare, B., Galle, S., Hanan, N., Kergoat, L., Levis, S. and Seguis, L. (2009). AMMA-CATCH studies in the Sahelian region of West-Africa: an overview. *Journal of Hydrology*, 375(1), 3-13.
- Lake Chad Basin Commission (LCBC). (n.d.). Mandate and missions. Retrieved from <http://www.cblt.org/en/mandate-and-missions>

- Lake Chad Basin Commission (LCBC). (2013). The 58th Council of Ministers of the LCBC. Retrieved from <http://www.cblt.org/en/58-th-council-ministers-lcbc>
- Laraque, A., Mahe, G., Orange, D., and Marieu, B. (2001). Spatiotemporal variations in hydrological regimes within Central Africa during the XXth century. *Journal of Hydrology Amsterdam*, 245, 104-117
- LEADERSHIP. (2013). River Basin: Niger Introduces Technical Synergy on Agriculture. Retrieved from <http://leadership.ng/news/050713/river-basin-niger-introduces-technical-synergy-agriculture>
- Lebel, T., Diedhiou, A., and Laurent, H. (2003). Seasonal cycle and interannual variability of the Sahelian rainfall at hydrological scales (DOI: 10.1029/2001JD001580). *Journal of Geophysical Research*, 108.
- Legates, D. R., Lins, H. F., and McCabe, G. J. (2005). Comments on “Evidence for global runoff increase related to climate warming” by Labat et al. *Advances in Water Resources*, 28(12), 1310-1315.
- Liersch, S., Cools, J., Kone, B., Koch, H., Diallo, M., Reinhardt, J., Fournet, S., ... Hattermann, F. F. (November 01, 2012). Vulnerability of rice production in the Inner Niger Delta to water resources management under climate variability and change. *Environmental Science and Policy*.
- LLamball, R., Nelson, V., and Nathaniels, N. (2011). Emerging approaches for responding to climate change in African agricultural advisory services. Retrieved from http://www.fara-africa.org/media/uploads/library/docs/fara_publications/afaas_climate_change_ver09.pdf
- Lu, J. and Delworth, T.L. (2005). Oceanic forcing of the late 20th century Sahel drought. *Geophys. Res. Lett.* 32.
- Luc Descroix, and Okechukwu Amogu. (2012). Consequences of Land Use Changes on Hydrological Functioning. INTECH Open Access Publisher.
- Mahe, G., and Olivry, J. (1999). Assessment of freshwater yields to the ocean along the intertropical Atlantic coast of Africa (1951–1989). *Comptes Rendus De L'académie Des Sciences - Series Iia - Earth and Planetary Science*, 328(9), 621-626
- Mahe, G., Paturel, J. E., Servat, E., Conway, D., and Dezetter, A. (2005). The impact of land use change on soil water holding capacity and river flow modelling in the Nakambe River, Burkina-Faso. *Journal of Hydrology Amsterdam*, 300, 33-43
- Malam, R. L. S. W. A., and Mikolasek, M. P. M. O. (2004). Review of the present state of the environment, fish stocks and fisheries of the river Niger (West Africa). In SYMPOSIUM ON THE MANAGEMENT OF LARGE RIVERS FOR FISHERIES VOLUME (p. 199).
- McCartney, M., Forkuor, G., Sood, A., Amisigo, B., Hattermann, F., and Muthuwatta, L. (2012). The water resource implications of changing climate in the Volta River Basin. International Water Management Institute (IWMI).
- Milich, L., and Varady, R. G. (1999). Openness, sustainability, and public participation: New designs for transboundary river basin institutions. *The Journal of Environment and Development*, 8(3), 258-306.
- Milly, P. C., Dunne, K. A., and Vecchia, A. V. (2005). Global pattern of trends in streamflow and water availability in a changing climate. *Nature*, 438(7066), 347-350.
- Muriuki, G. W., Njoka, T. J., Reid, R. S., and Nyariki, D. M. (2005). Tsetse control and land-use change in Lambwe valley, southwestern Kenya. *Agriculture, ecosystems and environment*, 106(1), 99-107.

- National Adaptation Plan of Action. (n.d.). National Adaptation Plan of Action. Retrieved from www.napa-pana.org/private/modules/knowledgebox/io/file.php
- Newbold, J. D., O'Neill, R. V., Elwood, J. W., and Winkle, W. V. (1982). Nutrient Spiraling in Streams: Implications for Nutrient Limitation and Invertebrate Activity. *The American Naturalist*, 120, 5.
- Niasse, M., Afouda, A., and Amani, A. (Eds.). (2004). Reducing West Africa's vulnerability to climate impacts on water resources, wetlands, and desertification: elements for a regional strategy for preparedness and adaption. IUCN--the World Conservation Union.
- Niasse, M., Iza, A., Garane, A., Varis, O., International Union for Conservation of Nature and Natural Resources., Atelier de l'UICN : "Gouvernance de l'eau : aspects juridiques et institutionnels de la gestion des ressources naturelles en Afrique de l'Ouest", and IUCN Workshop : "Water Governance : Legal and Institutional Aspects of Natural Resources Management in West Africa". (2004). La gouvernance de l'eau en Afrique de l'Ouest: Aspects juridiques et institutionnels : Compte rendu de l'atelier de l'UICN "Gouvernance de l'eau : aspects juridiques et institutionnels de la gestion des ressources naturelles en Afrique de l'Ouest." Ouagadougou, Burkina Faso, 25-27 septembre 2002. Water governance in West Africa: legal and institutional aspects : proceedings of the IUCN workshop "Water governance : legal and institutional aspects of natural resources management in West Africa". Gland: IUCN
- Nicholson, S. (2000). Land Surface Processes and Sahel Climate. *Reviews of Geophysics*, 38, 117-140.
- Nicholson, S.E. (2005). On the question of the "recovery" of the rains in the West African Sahel. *Journal of Arid Environments* 63(3), 615-641.
- Nilsson, C., and Renöfält, B. M. (2008). Linking flow regime and water quality in rivers: a challenge to adaptive catchment management. *Ecology and Society*, 13(2), 18.
- Nubukpo, K., and Galiba, M. (June 1999). Agricultural Intensification in West Africa: Insights from Sasakawa Global 2000's Experience. In workshop on Agricultural Transformation, Nairobi, Kenya.
- Offem, B. O., Akegbejo-Samsons, Y., and Omoniyi, I. T. (2010). Aspects of Ecology of *Clarias anguillaris* (Teleostei: Clariidae) in the Cross River, Nigeria. *Turkish Journal of Fisheries and Aquatic Sciences*, 10(1), 101-110.
- Oguntunde, P. G., and Abiodun, B. J. (2013). The impact of climate change on the Niger River Basin hydroclimatology, West Africa. *Climate Dynamics*, 40(1-2), 81-94.
- Oguntunde, P. G., Friesen, J., van. G. N., Savenije, H. H. G., and Time Series Analysis in Hydrology. (2006). Hydroclimatology of the Volta River Basin in West Africa: Trends and variability from 1901 to 2002. *Physics and Chemistry of the Earth*, 31(18), 1180-1188.
- Oki, T., and Sud, Y. C. (1998). Design of Total Runoff Integrating Pathways (TRIP)-A Global River Channel Network. *Earth Interactions*, 2(1), 1-37.
- Olsson, L., Eklundh, L., and Ardo, J. (2005). A recent greening of the Sahel—trends, patterns and potential causes. *Journal of Arid Environments*, 63(3), 556-566.
- OMVS. (n.d.). OMVS website. Retrieved from <http://www.portail-omvs.org>
- Opoku-Ankomah, Y. (2000). Impacts of Potential Climate Change on River Discharge in Climate Change Vulnerability and Adaptation Assessment on Water Resources of Ghana. Water Research Institute (CSIR), Accra. Ghana.

- Organisation for Economic Co-operation and Development (OECD). (2008). Climate and Climate Change in West Africa. Retrieved from http://www.fao.org/nr/clim/docs/clim_080502_en.pdf
- Organisation for Economic Co-operation and Development (OECD). (2010). Sahelian climate: past, current, projections. Retrieved from http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CC0QFjAA&url=http%3A%2F%2Fwww.oecd.org%2Fswac%2Fpublications%2F47092928.pdf&ei=zOX_UYaqEJPU9QT2plDIAG&usg=AFQjCNEExKieC2DjJnq0_sWbf28jWSua2EuA&sig2=ADOrXIl6PaCSqpy0nr0OTA&bvm=bv.50165853,d.eWU
- Oyebande, L., and Odunuga, S. (2010). Climate change impact on water resources at the transboundary level in West Africa: the cases of the Senegal, Niger and Volta Basins. *Open Hydrology Journal*, 4(1), 163-172.
- Pan Africa Chemistry Network (PACN). (2010). Africa's Water Quality a Chemical Science Perspective. Retrieved from <http://www.rsc.org/Membership/Networking/InternationalActivities/PanAfrica/waterreport.asp>
- Peluso, N. L., and Watts, M. J. (Eds.) (2001). *The Violent Environments: Social Bonds and Racial Hubris*. Cornell University Press.
- Petra, D., and Hannes, M. S. (2012). How is the impact of climate change on river flow regimes related to the impact on mean annual runoff? A global-scale analysis. *Environmental Research Letters*, 7, 1.
- Pickaver, A., and Sadacharan, D. (2007). The Benefits of Inter-linking Coastal and River Management. Retrieved from http://www.gpa.depiweb.org/docman/doc_view/192-the-benefits-and-the-challenges-of-linked-coastal-and-river-basin-management-case-studies.html
- Raadgever, G. T., Mostert, E., Kranz, N., Interwies, E., and Timmerman, J. G. (2008). Assessing management regimes in transboundary river basins: do they support adaptive management. *Ecology and Society*, 13(1), 14.
- Roudier, P., and Mahe, G. (2010). Calcul des pluies et debits classes sur le bassin du Bani (Mali): une approche de la vulnerabilite des ouvrages et de la population depuis la secheresse. *Hydrological Sciences Journal*, 55(3), 351-363.
- Shanahan, T. M., Overpeck, J. T., Anchukaitis, K. J., Beck, J. W., Cole, J. E., Dettman, D. L., and King, J. W. (2009). Atlantic forcing of persistent drought in West Africa. *Science*, 324(5925), 377-380.
- Slettebak, R. T. (2012). Don't blame the weather! Climate-related natural disasters and civil conflict. *Journal of Peace Research*, 49(1), 163-176.
- Solomon, S. I., Beran, M., Hogg, W. D., and International Union of Geodesy and Geophysics. (1987). *The Influence of climate change and climatic variability on the hydrologic regime and water resources*. Wallingford, Oxfordshire, U.K: International Association of Hydrological Sciences.
- The African Development Bank, (2013). Lake Chad Basin Commission Seeks AfDB Support. Retrieved from <http://www.afdb.org/en/news-and-events/article/lake-chad-basin-commission-seeks-afdb-support-11998/>
- The International Union for Conservation of Nature (IUCN). (n.d.). Volta River Basin. Retrieved from <http://www.waterandnature.org/en/results/wani-basins/volta>
- The Lake Chad Basin Commission (LCBC). (2013). Climate. Retrieved from <http://www.cbtl.org/en/climate>

- The Lake Chad Basin Commission (LCBC). (n.d.). The management team. Retrieved from <http://www.cblt.org/en/managements-team>
- The Organisation pour la mise en valeur du fleuve Sénégal (OMVS), (2013). Interview du haut commissaire de l'OMVS. Retrieved from <http://www.portail-omvs.org/actualite/interview-du-haut-commissaire-lomvs>
- Theisen, O. M. (2012). Climate clashes? Weather variability, land pressure, and organized violence in Kenya, 1989–2004. *Journal of Peace Research*, 49(1), 81-96.
- Thiam, E. H. I., and Singh, V. P. (2004). Space-time-frequency analysis of rainfall, runoff and temperature in the Casamance River basin, southern Senegal, West Africa. *Water SA*, 28(3), 259-270.
- Turner, M. D. (2004). Political ecology and the moral dimensions of “resource conflicts”: the case of farmer–herder conflicts in the Sahel. *Political geography*, 23(7), 863-889.
- Uhlir, P. F. (2002). Scientific Data for Decision Making Toward Sustainable Development: Senegal River Basin Case Study: Summary of a Workshop. National Academies Press.
- UNEP (2008), “Africa: Atlas of Our Changing Environment.” Division of Early Warning and Assessment (DEWA) United Nations Environment Programme (UNEP): Nairobi, Kenya.
- UNESCO (n.d.). World Wide Assessment Program. Retrieved from http://webworld.unesco.org/water/wwap/case_studies/senegal_river/
- United Nation High Commissioner for Refugees. (2011). Summary of Deliberations on Climate Change and Displacement. Retrieved from <http://www.refworld.org/pdfid/4d9f22b32.pdf>
- United Nations Development Programme (UNDP). (2013). Human Development Report 2013. The Rise of the South: Human Progress in a Diverse World. Retrieved from http://hdr.undp.org/en/media/HDR_2013_EN_complete.pdf
- United Nations Environment Programme (UNEP). (2008a). “Africa: Atlas of Our Changing Environment.” Division of Early Warning and Assessment (DEWA) United Nations Environment Programme (UNEP). www.unep.org/dewa/africa/africaAtlas/PDF/en/Africa_Atlas_Full_en.pdf
- United Nations Environment Programme (UNEP). (2008b). Freshwater Under Threat: Vulnerability Assessment of Freshwater Resources to Environmental Change – Africa. 2008, UNEP and WRC – South Africa. Retrieved from http://www.unep.org/dewa/Portals/67/pdf/Freshwater_under_Threat_Africa_Pub_72dpi.pdf.
- United Nations Environment Programme (UNEP). (2011). Livelihood Security Climate Change, Migration and Conflict in the Sahel. Retrieved from http://www.unep.org/pdf/UNEP_Sahel_EN.pdf
- United Nations Environment Programme (UNEP). (n.d.). Improving the Quantity, Quality and Use of Africa’s Water. Retrieved from http://na.unep.net/atlas/africaWater/downloads/chapters/africa_water_atlas_123-174.pdf
- United Nations Environment Programme (UNEP). (n.d.). Causal chain analysis. Retrieved from http://www.unep.org/dewa/giwa/areas/reports/r41/causal_chain_analysis_giwa_r41.pdf
- United States Environmental Protection Agency (EPA). (n.d.). Retrieved from <http://www.epa.gov/>
- UUNEP, DH-Center for Water and Environment. (2007). The Benefits and the Challenges of Linked Coastal and River Basin Management. Retrieved from

- http://www.gpa.depiweb.org/docman/doc_view/192-the-benefits-and-the-challenges-of-linked-coastal-and-river-basin-management-case-studies.html
- Vannote, R.L., Minshall, G.W., Cummins, K.W., Sedell, J.R., and Cushing, C.E. (1980). The river continuum concept. *Canadian journal of fisheries and aquatic sciences*, 37(1), 130-137.
- Vigaud, N., Roucou, P., Fontaine, B., Sijikumar, S., and Tyteca, S. (2011). WRF/ARPEGE-CLIMAT simulated climate trends over West Africa. *Climate Dynamics*, 36(5-6), 925-944.
- Volta Basin Authority (VBA). (2007). Convention portant statut de fleuve Volta et creation de l'Autorite du Basin de la Volta. Retrieved from <http://www.abv-volta.org:10000/abv2/about/mandats-et-objectifs/convention-version-fr>
- Volta Basin Authority (VBA). (n.d.). Mandate and objectives. Retrieved from <http://www.abv-volta.org:10000/abv2/about/mandats-et-objectifs>
- Volta Basin Authority (VBA). (n.d.). Documentation. Retrieved from <http://www.abv-volta.org:10000/abv2/documents>
- Volta Basin Authority (VBA). (2008). Charte de l'eau. Retrieved from http://www.abn.ne/index.php?option=com_content&view=category&layout=blog&id=14&Itemid=10&lang=en
- Volta Basin Authority (VBA). (2011). Financial Partners. Retrieved from <http://www.abv-volta.org:10000/abv2/financialpartners>
- Volta Basin Authority (VBA). (2012). Programs and projects. Retrieved from <http://www.abv-volta.org:10000/abv2/projects>
- Wetlands International (2010). Guinea Bissau: mangroves in frontline against climate change. Retrieved from <http://www.wetlands.org/?TabId=60&articleType=ArticleView&articleId=2117>
- Wolf, A.T. and Newton, J.T. (2008). Case Studies of Transboundary Dispute Resolution. Appendix C in, Delli Priscoli, Jerry and Aaron T. Wolf. *Managing and Transforming Water Conflicts*. Cambridge: Cambridge University Press.
- World Bank. (2009). Africa Region – Senegal River Basin Water and Environmental Management Project. Washington D.C.: The World Bank. Retrieved from <http://documents.worldbank.org/curated/en/2009/01/10975321/africa-region-senegal-river-basin-water-environmental-management-projec>
- World Wide Fund for Nature (WWF). (2003). Agricultural water use and river basin conservation. Retrieved from <http://assets.panda.org/downloads/agwaterusefinalreport.pdf>

U.S. Agency for International Development

1300 Pennsylvania Avenue, NW

Washington, DC 20523

Tel: (202) 712-0000

Fax: (202) 216-3524

www.usaid.gov