



Building Resilience in African Hotspots: Learning from Collaborative Research

Sarah Czunyi and Bruce Currie-Alder

Contents

Introduction	2
African Hotspots in a +1.5 °C World	3
Adaptation Is About People	5
Effectiveness Through Lived Experience	9
Collaborative Research Across Hotspots	13
Conclusion	15
References	17

Abstract

Adaptation in Africa’s climate hotspots is context-specific, yet there is value in sharing lessons across sites with geographic and social similarities. Based on collaborative research conducted across 15 countries, this chapter addresses three questions in the hope of better understanding the resilience of people adapting to a changing climate. The first question is: what is the difference between 1.5 and 2 degree of global warming? Many parts of Africa, especially semi-arid lands, are warming faster than the global average with near-term consequences for agriculture, energy, and water. The second question is: how do gender and social difference shape who is vulnerable to climate change? People’s experience of climate change, and their ability to adapt to it, depends on age, gender, class, wealth, and ethnicity. Where someone lives also shapes their exposure, while the decision to migrate can diversify risk and alter household dynamics. The third question is: what is the effectiveness of adaptation from the lived experience of people and communities? Beyond government-led plans, a substantial amount of

Supplementary Information: The online version of this chapter (https://doi.org/10.1007/978-3-030-22759-3_328-1) contains supplementary material, which is available to authorized users.

S. Czunyi (✉) · B. Currie-Alder
International Development Research Centre, Ottawa, Canada
e-mail: sczunyi@idrc.ca; bcurrie-alder@idrc.ca

adaptation happens autonomously as individuals, households, companies, and private actors address the climate risks that affect them, their livelihoods, and their supply chains. Moving forward, climate change adaptation in Africa must work at scale to connect efforts across boundaries. This can be supported through a new generation of collaborative research with a focus on the needs of practitioners and decision-makers to inform future action.

Keywords

Climate change · Adaptation · Gender · Migration · Private sector

Introduction

Given the scale, urgency, and severity of climate change, adaptation is needed in the present and not only in the future. While all countries and regions of the world face this challenge, Africa and its people are among the most vulnerable places and populations – with climate change threatening to undermine years of progress toward global development goals and improvements to human well-being. Among the more vulnerable landscapes are semi-arid lands and river deltas, regions that are home to more than one billion people across Africa and South Asia. The concept of climate “hotspots” describes areas where a strong climate change signal combines with a large concentration of vulnerable, poor, or marginalized people (De Souza et al. 2015). Studying such hotspots, including their similarities across different regions, provides novel opportunities to understand how vulnerability is shaped by the biophysical environment, the livelihoods practiced within it, and the interactions between them. It has helped researchers and practitioners to understand that vulnerability is influenced by a range of factors – economic, physical, and sociocultural – as the people with the greatest vulnerability are not only highly exposed to climate risk but also rely on livelihoods that depend upon the environment.

This chapter addresses three fundamental questions underpinning the resilience of people adapting to a changing climate, based on findings from collaborative research comparing hotspots across Africa and South Asia: What are local climate impacts expected under 1.5 and 2 degree of global average warming? How do gender and social difference shape who is vulnerable to climate change? And what is the effectiveness of adaptation from the viewpoint of the lived experience of people and communities? The next three sections deal with each of these fundamental questions in turn, drawing on accumulated evidence ranging from peer-reviewed journal articles as well as practitioner-facing reports and grey literature, grounded in work carried out in Botswana, Burkina Faso, Ethiopia, Ghana, Kenya, Mali, Namibia, and Senegal. A final section examines the role of collaborative research itself, reflecting on how adaptation in Africa can work at scale to connect efforts across boundaries. This collaborative approach requires a new generation of research focused on the needs of practitioners and decision-makers to inform future action to enhance the resilience of people living in climate hotspots. In so doing, the

conclusion outlines a vision for learning and collaboration for the climate change research community at large.

African Hotspots in a +1.5 °C World

Despite global efforts to address climate change, human-induced global warming has already surpassed +1.1 °C above pre-industrial levels (WMO 2019). Over this century, the IPCC projects a further increase of between 0.1 °C and 0.3 °C per decade (IPCC 2018). The Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) commits the international community to keep global average temperatures “well below 2 °C” and in “pursuing further efforts to limit the temperature increase to 1.5 °C” (UNFCCC 2015). Yet when this agreement was made in 2015, there was limited information on what difference half a degree might make and how these temperature increments would affect parts of Africa. A call from the IPCC to contribute new evidence toward a special report on global warming of 1.5 degree prompted a surge in new research and evidence to understand the differential impacts of 1.5 and 2 degrees of warming in diverse locations. Downscaling projected impacts from global models to the regional or country level, novel research has addressed this knowledge gap and provided insights into how global warming will affect climate hotspots in Africa.

Our first fundamental question is: what are local climate impacts expected under 1.5 °C and 2 °C of global average warming? Unsurprisingly, Africa’s hotspots are warming faster than the global average. At least 44 African countries will warm more than the global mean increase of +1.5 °C, with 11 of them warming by over 25% more than the global mean change (New et al. 2019). The impacts of such warming include longer heat waves, hotter days, and more intense rainfall events. Together these impacts will give rise to significant changes in rainfall and increases in water scarcity and water stress. Small differences in the global average have more pronounced impacts in these more sensitive settings, with parts of Africa expected to surpass the 1.5 °C limit before 2030. Indeed, both the 1.5 and 2 °C thresholds are likely to be reached within the coming three decades, highlighting the urgent need for local adaptation strategies and action.

The effects of progressive increases in warming have been identified for semi-arid lands in Botswana, Ethiopia, Ghana, Kenya, Mali, and Namibia. Each country faces unique changes in temperature, rainfall, and climate extremes at each interval of global temperature increase (Video 1). In turn, these differential and increasing impacts have varied consequences for vulnerable sectors such as agriculture, water, health, and fisheries. In Botswana, for example, 1.5 °C of global warming translates into a 2.2 °C increase in mean local temperature with 5% decrease in already scarce rainfall. Heat wave conditions, with temperatures above 30 °C, are expected to occur for more than 6 weeks (44 days) of each year. In contrast, 2 °C of global warming translates into a 2.8 °C increase in Botswana with 9% decrease in precipitation. Heat waves will occur for more than 10 weeks (73 days) of the year, thus covering one-fifth of all days (Nkemelang et al. 2018).

Many semi-arid lands already rely on water flowing from adjacent geographies that experience wetter conditions. With warming of 1.5 °C and above, inland deltas, rivers, dams, and groundwater are all adversely affected. Declining groundwater stocks pose significant challenges to semi-arid communities. In the Klela Basin in Mali, for example, groundwater recharge will drop by over one-third under 1.5 °C of warming and reach zero net recharge by 3 °C of warming (Toure et al. 2017). Yet not all semi-arid regions studied will get drier. Kenya, Ethiopia, and Ghana are projected to experience a net increase in precipitation, although changes in the timing and quantity of this rainfall still have profound impacts on livelihoods.

People in semi-arid lands who are especially vulnerable are those that rely on climate-sensitive livelihood activities, such as rain-fed farming and pastoralism. Overall agricultural and livestock productivity is expected to decline due to the direct and indirect effects of local climate change. Crop yields are expected to fall by 15% beyond 2030, including millet, sweet potato, wheat, rice maize, soybean, and groundnut (Dupar 2019). Even at global warming of +1.5 °C, a total of 14.3 million livestock holder families in East Africa may be affected by falling productivity of cattle related to their heat sensitivity (O'Neill 2020). The well-being and health of these communities will also be affected. The distribution of malaria is shifting, and increased heat stress adds to health risks. At 3 °C of global warming, many parts of Africa will experience year-round risk of heat exhaustion (New et al. 2019).

The physical impacts of global warming are felt less immediately within coastal deltas due to the dynamic nature of these environments. Yet deltas are already impacted by increasing storm intensity, coastal erosion, periodic flooding, and salinization that undermines local livelihoods (Codjoe et al. 2020). Before 2040, the likely differences in sea-level rise and increased river flows between 1.5 and 2 °C of global warming are driven more by annual variability. Yet beyond 2 °C of global warming, nearly all delta regions will be exposed to significant flooding by 2200 (Brown et al. 2018). At present, most of the land area (88%) in the Volta Delta in Ghana lies below 5 m in elevation. Even under moderate warming of 1.5 °C, at least half of this land area may be exposed to the sea by 2200. Beyond 2 °C of global warming nearly the entire delta will be exposed. The differential effects of climate change mitigation and controlled sedimentation are key to delta survival over multi-centennial timescales – which requires maintaining a delta's height (IPCC 2018; Brown et al. 2018).

While the impacts of climate change dominate public discourse, they interact with other drivers and broader environmental changes across Africa's climate hotspots. For example, beyond the climate-driven factors such as sea-level rise and storms, subsidence and salinization in river deltas are also produced by water infrastructure and abstraction upstream that alters the flows of water and cuts off the supply of sediment. The rates of socioeconomic change in river deltas are so high in recent and near-future decades that they all but swamp climate signals, apart from short-run effects of extreme events such as cyclones (Apeaning Addo et al. 2018). Taking such complexities into consideration must become part of any efforts to enhance adaptation in different contexts.

The local climate impacts are notable under 1.5 °C of global average warming, and more pronounced at 2 °C of global average warming. Although little was known in 2015 on what difference half a degree might make, we now know that Africa's hotspots are warming faster than the global average, leading to longer heat waves, hotter days, and more intense rainfall. Inland deltas, rivers, dams, and groundwater are all adversely affected, with declining groundwater and reduced water availability for adjacent geographies. Heat stress and constrained water supply limit agricultural and livestock productivity. Parts of Africa are expected to surpass the 1.5 °C limit before 2030, highlighting the urgent need for local adaptation strategies and action.

Adaptation Is About People

Our second fundamental question is: how do gender and social difference shape who is vulnerable to climate change? Efforts to strengthen adaptive capacities seldom acknowledge the gendered nature of everyday realities and experiences. Gender roles and responsibilities shape women's and men's access to, ownership of, and control over resources, as well as capacities to respond to stress caused by climate change. The existing literature recognizes gendered experiences of climatic change, with poorer women and female-headed households as the most vulnerable. Yet this work also tends to undervalue women's agency and ignore other forms of social difference (Rao et al. 2019a). New evidence challenges the notion that all women are inherently vulnerable (Maharjan et al. 2020) and highlights that there are different social factors beyond gender that can make individuals or communities vulnerable. Empowerment requires taking into account the resources available to people and how they use those resources. Entrenched social structures and power relations shape adaptive capacity in complex ways, and people exercise their agency by drawing on various strategies. Examining how vulnerability is differentiated requires moving beyond simple comparisons of women and men, or stereotypes of women as powerless victims of climate change (Video 2).

Across vulnerable hotspots, from the semi-arid lands of Kenya and Ethiopia to the deltas of Ghana, men are migrating as their families experience waves of floods, droughts, landslides, or extremes of uncertainty. The wages they are able to send home may be vital to family survival, but their absence also heightens the workload assumed by women, who not only provide care for children and the elderly but also labor needed to tend to farms and livestock. In general, as environmental stress increases across hotspots in Africa, it tends to reduce women's agency even in the face of supportive household structures, laws, and social norms. Gender roles trap impoverished women in a cycle of low productivity, indebtedness, and food insecurity, particularly when crops fail or livestock suffer ill health. While the specifics of gender relations vary in each location, community support networks tend to break down as environmental stresses accumulate. Women in hotspots report reduced leisure time, with negative consequences for their own well-being and for household health and nutrition (Rao et al. 2019b).

While gender is one of the dimensions of social difference, it intersects with many others. For example, while social networking is important for female entrepreneurs in Narok, Kenya, those who are best able to maximize these opportunities also benefit from other advantages such as education (Atela et al. 2018). Women's and men's adaptation choices are influenced by their status and assets, the rules and norms under which they live, what makes them unique as individuals, as well as their standing within and connection to wider society. Across Africa, a high proportion of micro- and small businesses are women-led and face high exposure to climate risk. Despite limited access to finance and limited legal protection, women entrepreneurs have significant adaptive capacity that can be harnessed. Yet financial and legal barriers can force women entrepreneurs into unsustainable forms of coping that reduce profits or even end a business (Atela et al. 2018). In addition to addressing inequalities, given women's double burden, building resilience at the household level could support adaptive capacity among female-led businesses.

Increasing climate risks can alter household dynamics, whether driving conflict within the home or fostering new forms of cooperative behavior (Rao et al. 2020). Within agrarian families, men and women typically play different roles, but these roles can be complementary in helping families diversify and increase their resilience, tapping strategies such as livelihood diversification, migration, adopting new farming practices, or accessing social supports. Diversification is an important household coping strategy, with gender norms shaping the possibilities open to men and women within households and communities. In the Upper West Region of Ghana, for example, men often migrate during the dry season, while women supplement their income by selling firewood and making shea butter or soap (Rao et al. 2020). While climate change adds to women's workload, adaptation can transform social relations and create new roles for both men and women.

Gender relations are changing in terms of divisions of work and responsibilities across scales from the household and community to markets and the state. Beyond simply addressing women's physical exposure to climate risk, adaptation efforts can recognize and foster women's economic and productive contributions, such as ensuring access to credit and land. Measures that enhance women's agency enable greater control over their lives and more opportunity to adapt to a changing climate, for example, through favorable access to and safety of women in markets, financial transactions, and public spaces. In short, adaptation must consider gender equality and social inclusion, as a complementary means of improving people's well-being alongside more biophysical options of responding to climate risk. More attention is needed on masculinities, or the gendered roles and changing expectations placed upon men. As climate change pushes both women and men into new roles and spaces, it is fostering new forms of cooperation and challenging traditional views on who is responsible for providing care, earning income, and managing assets.

How and why does vulnerability vary between communities, within households, and what do these differences mean for adaptation? Use of mixed research methods – including surveys, focus group discussions, and life history interviews – reveals that the agency of individuals and households is affected not just by the individual characteristics such as age, ethnicity, class, and marital status but by social systems

and structures (Rao et al. 2019a). An intersectional framing considers multiple influencing factors to illuminate nuances in responses to climate change. This can result from the ways in which gender intersects with factors such as age, caste, and ethnicity to either augment or diminish vulnerability.

As climate change erodes the productive potential of rural livelihoods, or endangers families where they live, those who can may choose to move elsewhere. Debates on climate-induced migration have sought to estimate the numbers of people potentially displaced by future impacts (Rigaud et al. 2018), while media have speculated over potential humanitarian crises and mass migration of “climate refugees.” Yet more than 90% of migrants from Africa’s climate hotspots remain on the continent, and worldwide the vast majority of migrants remain within their own borders or regions (O’Neill 2020). This reality demands understanding of the circumstances under which migration offers a better life for those who move, as well as for those who remain behind. Migration may be characterized as an adaptation strategy if it helps households to spread risk and diversify incomes. Yet migration may also result from the failure to adapt in place as households are unable to satisfy their needs. Much nuance is hidden between these two extremes and depends on the specific reasons for moving as well as the dynamics of who migrates, for what purpose, to which locations, and whether this is seasonal or prolonged over time.

The effects of migration, positive and negative, are felt in both sending and receiving communities, those places experiencing outmigration and immigration. Studies have found that migration can increase households’ resilience to climate impacts on vulnerable livelihoods (Qaisrani and Salik 2018). Yet migration does not always lead to a better life. Those most vulnerable to environmental stress are often at the mercy of structural inequalities, such as class, or other forms of social discrimination, that remain constant regardless of their location. The potential benefits of rural-urban migration are also undermined by the explosive growth of informal settlements in cities that are receiving migrants (Singh and Basu 2019; Qaisrani and Salik 2018). Migrants can end up worse off in their destinations, suffering a sense of dislocation without state recognition and lack of attention to their needs.

As different family members pursue opportunities, “households” are better understood as social networks with nodes in multiple locations rather than merely cohabiting in a single family home. These networks shape how households manage risk and identify and pursue adaptation options (Singh 2019). Thus migration makes households more interconnected across distant places. Men and women migrants can contribute to adaptation back home, supporting relatives and themselves as they face different risks and opportunities. Migration poses risks for both individuals and households. Remittances, skill acquisition, and transfer are all important contributions to adaptation at the household level (Maharjan et al. 2020). Migration, however, does not always improve lives and livelihoods, as migrants are exposed to different risks and hazards in the destinations, and their absence can heighten the exposure of those who are left behind and unable to move. Debates on whether

migration is an adaptation strategy tend to ignore the immobility of the poorest and potential erosion in well-being of both migrants and their households.

Few people self-identify as environmentally displaced, but instead climate change tends to be an indirect incentive to migrate. People describe their motivation to move as seeking better livelihoods and economic opportunities. Digging deeper, research has revealed that environmental degradation or extreme weather does play a role in diminishing livelihood prospects in their places of origin, reducing incomes, and heightening the attractiveness of moving away. In examining where people live and move in deltas, more than one-third of surveyed households report having at least one member of the family who has moved away (de Campos et al. 2020). While less than 3% of these respondents attributed migration to environmental stress, their households face significant exposure to environmental risks and economic insecurity associated with environmental hazards. One-third of all respondents had observed an increased exposure to hazards in recent years, such as cyclones, drought, erosion, flooding, salinity, and storm surges. Similarly, between 40 and 80% of respondents associated environmental factors with more insecure livelihoods, suggesting an underlying link between environmental degradation, insecurity, and the migration of household members (Conway et al. 2019).

Migration is changing households and communities. In Ghana's Volta Delta, for example, most outmigration from the delta is permanent rather than seasonal. People identify the drivers of outmigration as seeking employment, education, or to be reunited with family members. Given the large numbers of people on the move, mostly men, this has led to demographic changes in the Volta Delta population. The ratio of men-to-women is lower than the national average, while the proportion of female-headed households is higher. While few individuals cite direct environmental factors to their decision to migrate, flooding and erosion nonetheless limit the prospects for farming and fishing by reducing the land available for crops and landing sites (Codjoe et al. 2020).

Under certain conditions, migration can be an adaptation option with the potential to increase social resilience to climate change. Yet the decision to move involves a complex set of choices for each individual and family. In trying to better understand these motivations, and whether migration can actually increase resilience, researchers need to appreciate the hopes, aspirations, and trade-offs faced by individuals *within* households. Life history interviews offer a promising method from anthropology that can be applied to studying risks and responses to climate change. Researchers have begun to use this method and produced guidance on conducting life history interviews (Singh et al. 2019; Davies et al. 2018). Among the benefits, life history captures the interactions among varied drivers of behavior and reveals the interplay of past, present, and future motives, aspirations, and values. Such bottom-up methods delve into the extent people rely on the natural environment and how they experience diverse shocks over time. For example, how do farming households respond to repeated floods and droughts over consecutive years, and whether the accumulated responses place people on a pathway to resilience or increasing vulnerability.

Future work needs to probe how climate stresses play out in society and why some people adapt while others do not. This is often overlooked in more top-down approaches to studying climate adaptation (Conway et al. 2019). Moving forward, research needs to examine how slow- and rapid-onset impacts intermingle with climate-reliant livelihoods, combining environmental and economic reasons for why and where people decide to move and live. Understandings of migration needs to look beyond simplistic correlations and probing the deeper causes of vulnerability and how people respond to a changing climate.

Effectiveness Through Lived Experience

Our third fundamental question concerns the effectiveness of adaptation from the viewpoint of the lived experience of people and communities. The rapid pace of warming in Africa's hotspots, together with their vulnerable populations, underscores the urgency of adaptation. Yet there is surprisingly little consensus on what effective adaptation looks like, whom it should benefit, or how it should be approached and measured (Tompkins et al. 2018). The Paris Agreement establishes a qualitative "global goal on adaptation" (Article 7) and calls for assessing progress at a global stock-take starting in 2023 and then every 5 years. One approach to assessing the effectiveness of adaptation is to compare the level of investment or effort against national plans and aggregate those national experiences in the global stock-take exercise. Yet an increasing level of attention is being paid to the local level and the lived experience of communities. Such a perspective offers fresh insight grounded in real-world testing of adaptation options and response in the real economy by households and businesses.

In Africa, the burden of a changing climate often falls most heavily on those already disadvantaged by poverty and powerlessness. This means adaptation is inseparable from questions of equity and justice: who benefits, who pays, and who has a voice in shaping adaptation strategies. What constitutes effectiveness must go beyond the mere existence of plans and policies, to embrace what makes each community unique, including specific climate risks, aspirations, barriers, and capacities. Adaptation is inherently local and an ongoing process of continued adjustment to changing climatic conditions. Provocatively, some authors argue that the notion of adaptation "success" is flawed. Pursuing a universal, yet abstract, measure of effectiveness may be less fruitful than probing how local people and communities appreciate adaptation and their level of satisfaction with it. People must be empowered to define success in terms that are most meaningful to them (Dilling et al. 2019).

Research on Africa's semi-arid lands identifies multiple barriers and enablers that, respectively, impede or catalyze adaptation (Few et al. 2018). Barriers are factors that make it harder to achieve adaptation outcomes, while enablers are those that make it easier. Water availability, for example, can be restricted by weak governance rules yet increased by investment in water storage infrastructure. Numerous case studies highlight the value of mapping and addressing such potential interactions in

the design of adaptation interventions. For example, in Mali, a regulation intended to facilitate farmer access to high-quality seed, yet the local conditions in which farmers operate created a barrier to implementing the regulation. Access to improved seeds was constrained by the administrative requirements facing farming associations in certifying the seeds they produce, forcing a reliance on selling through informal networks at a reduced price. Private companies emerged as intermediaries to pay for seed production and certification, yet at charged prices beyond what most smallholder farmers could afford (Few et al. 2018). In Namibia, government support for drought relief and pensions inadvertently encouraged dependence rather than building local capacity or promoting the uptake of climate-resilient farming techniques. Shortages of farm labor due to migration to towns also present a barrier to labor-intensive options such as water bunds and planting pits.

Ultimately what matters is not so much the overall level or “gap” of adaptation efforts but a deeper understanding of what encourages or prevents effective, widespread, and sustained adaptation that aligns with the aspirations of local communities. Knowledge needs to support adaptation for, and by, the poorer and often politically marginalized people facing environmental stress upon their livelihoods and well-being. Some efforts have sought to understand how different factors constrain or promote the chances of achieving success in adaptation, utilizing a normative framing of barriers and enablers, as explicit goals of how adaptation should proceed (Few et al. 2018).

Deficiency in information and lack of economic security are common barriers to undertaking adaptation. For example, farmers are unlikely to take on the risk of changing crops without strong enabling mechanisms. Specific intersecting barriers to adaptation include lack of coordination on planning between the national and local levels, the low capacity of communities to adapt, and their high dependence on natural resources (Davies et al. 2020). Decision-making at the local scale tends to rely on climate information over the daily to seasonal timescales, in formats that are readily understood and acted upon by farmers, pastoralists, and subnational governments. Longer-term climate projections, at the multiannual to decadal timescale, have been less readily accessible and are ill-suited to the real-world needs of these users. This gap suggests a need for using climate information, as well as increasing its accessibility, in ways that contribute both to coping and adaptation (Singh et al. 2018). Despite growing demand for climate information, it often remains difficult for practitioners to navigate the volume, quality, and relevance of what is available. This need has given rise to brokering efforts, such as produced summary guides on recent IPCC special reports to highlight the implications for Africa or training to communicate credible information through Wikipedia (Dupar 2019). Additional and creative efforts to enhancing collaboration among actors are essential to facilitate knowledge flow and uptake of adaptation knowledge by intended beneficiaries (Ofogebu et al. 2020).

Probing such barriers to adaptation and understanding the lived experience require a shift in methods, going beyond technocratic approaches to adaptation, such as dykes and borewells. For example, participatory modes of engaging with stakeholders, such as Transformative Scenario Planning and Vulnerability and Risk

Assessment, bring people together to address intersecting barriers and enablers. Participatory approaches to adaptation are based on input from local inhabitants (Scodanibbio and Morchain 2019) and can reveal connections between governance, social differentiation, ecosystem services, gender, and knowledge systems. People-centered bottom-up processes provide critical and practical information to inform adaptation and decision-making. Combining top-down and bottom-up assessments provides opportunities to integrate qualitative and quantitative methods to explore risk, vulnerability, and adaptation options (Conway et al. 2019).

Discussions of barriers and enablers in adaptation often focus on finance, technology, skills, institutional capacity, and governance. Yet these factors underappreciate the importance of what people perceive and believe in shaping the range of desirable and acceptable adaptation options, as well as the extent that these are acted upon and judged to be effective. Such considerations can be embedded in cultural structures – related to social status, caste, and gender – as well as within worldviews, values, norms, taboos, and behaviors. Understanding cultural dynamics is key, as deep-rooted traditions are confronted by rapid environmental and social change. There are multiple forms of barriers and enablers that interact to constrain or strengthen adaptation outcomes. Such barriers and enablers can also change over time. Understanding how interacting factors shape the conditions for successful development, uptake, and effectiveness of adaptation actions is critical for promoting adaptation.

The private sector has a vital role in determining whether societies become resilient to climate change. While semi-arid lands and marginal environments are often seen as problem landscapes and places of despair, targeted adaptation action by the private sector views them as productive landscapes and places of potential. Inhabitants of semi-arid lands rely heavily on rain-fed agriculture, pastoralism, and agricultural processing for their livelihoods, making them particularly exposed to climate and environmental variability. They are often also remote, politically and economically marginalized areas that have limited access to markets, infrastructure, and services. Yet governments and investors have tended to underestimate their economic opportunity and the potential benefit of business enabling environments that encourage a range of private actors to address climate risks in these contexts.

With the right investments and policy supports, climate-vulnerable sectors become economic assets that drive transformation toward greater resilience. Focusing on climate-resilient economic development in semi-arid lands requires recognizing the wealth of opportunities such areas offer for investment and action in supporting livelihoods. Semi-arid lands play an outsized role in their respective national economies. In the Horn of Africa, the livestock sector represents 10% of GDP and 40% of added value in agriculture. In Kenya alone, livestock contributes to around 12% of the country's GDP and employs roughly half the country's agricultural workforce (Bedelian et al. 2019). Public and private actors need to work with the variability, seasonality, and informality of dryland systems, strengthening productive sectors that contribute to trade and employment and realizing the twin goals of poverty and climate adaptation (Jobbins et al. 2018).

Value chain analysis offers a promising technique for pinpointing specific investment opportunities and potential solutions to safeguard the economic life of Africa's semi-arid lands. Examining value chains such as livestock and agriculture, regionally focused research has identified climate risk, adaptation options, and opportunities for private sector development in key economic sectors at the district level (Carabine and Simonet 2018). Itself a combination of bottom-up and top-down methods, work to date started with inputs from national stakeholders when examining value chains related to cotton (Burkina Faso) and livestock (Senegal, Kenya). With an appreciation of the economic sector, this method proceeds to map the value chain, assess climate risks at each link or step of production, and then identify specific adaptation and investment options that can increase resilience at more vulnerable links along the value chain.

Adaptation measures can strengthen firms, both formal and informal, and households in vulnerable regions. Recent evidence demonstrates that the private sector in semi-arid regions is actively responding to such risks by diversifying into activities, availing to insurance or loans, and taking steps to prepare for future climate change (Gannon et al. 2020). Work with female-led small and medium enterprises (SMEs) in semi-arid Kenya suggests that most are confined to agriculture – typically small-scale trade in cereals, milk, and poultry (Atela et al. 2018; Crick et al. 2018a). Through increased extreme temperatures, high rainfall variability, and fluctuations in grazing and water resources, these enterprises are highly exposed. Entrepreneurs link climate impacts and disease to reduced growth and losses for their businesses, such as when drought lowers livestock birth rates, cuts milk production, or reduces animals' weights and market value.

While there are many barriers to adaptation among private actors in semi-arid lands, these landscapes also feature strong social networks and diversified livelihoods that help people respond to climate variability. If these assets and approaches can be harnessed and scaled up, there are real opportunities for climate-resilient economic development, although not without a risk of maladaptive response. For example, a switch to water-intensive cash crops is clearly not sustainable. Yet more troubling is the question of why private actors do not proactively embrace opportunities to become more climate-resilient. Even as diverse sectors are exposed to climate risks, the formal private sector has not been investing in adaptation. For example, meat-processing firms in Kenya expect producers to bear the risks (Carabine and Simonet 2018). This lack of private investment suggests a need to better articulate the business case for adaptation, enabling regulation and public investment to incentivize and steer private adaptation in environmentally and economically sustainable directions.

There is a role to play for governments to enable adaptation in the private sector. A survey of 325 small and medium enterprises in semi-arid regions of Kenya and Senegal found that financial barriers and insufficient market access increase the probability of business contraction. In contrast, access to information, general government support, and specific adaptation assistance all increase the probability of sustainable adaptation (Crick et al. 2018b). Such findings point to a clear role for public policy in facilitating effective adaptation, as a firm's ability to respond to

climate risks depends on factors in the business environment that are shaped through policy intervention. Moreover, surveys suggest that the benefits of intervention are both immediate and long-term: the more firms engage in sustainable adaptation behavior, the more likely they are to start planning for future climate change, thus reducing their long-term vulnerability.

The lived experience of local communities and responses in the real economy by households and businesses offer fresh insights on what constitutes effective adaptation in practice. Adaptation is an ongoing process of continued adjustment, and people must be empowered to define success in terms that are most meaningful to them. Barriers are factors that make it harder to achieve adaptation outcomes, while enablers are those that make it easier. What matters is not so much the overall gap in adaptation efforts but a deeper understanding of what encourages or prevents effective, widespread, and sustained adaptation that aligns with the aspirations of local communities. Deficiency in information and lack of economic security are common barriers to undertaking adaptation. Probing such barriers requires going beyond “traditional” approaches to adaptation, for example, embracing participatory methods based on input from local inhabitants. The private sector has a vital role in determining whether societies become resilient to climate change. While semi-arid lands and marginal environments are often seen as problem landscapes and places of despair, targeted adaptation action by the private sector views them as productive landscapes and places of potential. With the right investments and policy supports, climate-vulnerable sectors can become economic assets that drive transformation toward greater resilience.

Collaborative Research Across Hotspots

Working across climate hotspots offers a transdisciplinary approach to framing and approaching climate impacts and adaptation. Despite being spread across different countries, a focus on hotspots highlights geographic and social similarities in the way people experience climate change. The insights described in the preceding sections emerged from collaborative research conducted through a set of four consortia from 2014 to 2018 (O’Neill 2020). A research consortium is a model of collaboration that brings together multiple individuals or organizations that are otherwise independent from one another, to address a common set of questions using a defined structure and governance model (Gonsalves 2014). Over 5 years, the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) contributed to over 20 local or national adaptation plans and strategies and to over a dozen policies in 11 countries (Lafontaine et al. 2018) (Thematic and regional summaries of “Adaptation at Scale in Semi-Arid Regions” are available at <http://www.assar.uct.ac.za/>). Further details on the research consortia are contained in final technical reports <http://hdl.handle.net/10625/57445>, <http://hdl.handle.net/10625/58343> and <http://hdl.handle.net/10625/57543>). CARIAA sought to generate high-quality research, encourage its uptake through stakeholder engagement, and increase capacity to design, communicate, and use research and evidence. By mid-2019, CARIAA

had produced 945 research outputs including 121 peer-reviewed journal articles and held 285 events reaching more than 9500 stakeholders, while 268 individuals benefited from capacity building such as graduate degrees, postdoctoral positions, and internships.

Such efforts demonstrate the potential for collaborative research to develop robust evidence on how to increase the resilience of vulnerable populations and their livelihoods in climate change hotspots. Collaborative research can tackle regional-scale challenges by bringing together actors across scientific disciplines, knowledge domains, and policy and practice (Cochrane et al. 2017), including partnerships among academic and nonacademic participants. Working through such a consortium offers opportunities to bring together the complementary strengths of universities, think tanks, NGOs, and government agencies. Bringing together diverse individuals and organizations provides opportunities for combining expertise and geographic scopes to share knowledge and experience across disciplines, sectors, and geographic areas. Recent literature highlights rising expectations within adaptation research with respect to transparency and consultation in research design, attention to the incentives that motivate participants, and consideration of career paths for early career researchers, as well as the critical functions of knowledge brokering, knowledge management, and learning (Jones et al. 2018).

Collaborative research brings together diverse partners that collectively bridge science, geography, and practice (Video 3). In terms of science, research on climate hotspots benefits from combining expertise across disciplines spanning from climate science to local economic development. It is also useful to include a mix of participants with different academic qualifications, experience with research and practice, and a range of orientations from the more scholarly to the more policy and practice focused. Some participants may have established track records authoring peer-reviewed publications and contributing to the scientific community, while others are rooted in the daily practice of government, communities, and business. In terms of geography, a focus on climate hotspots can benefit from having participants located in multiple countries and districts to elucidate what is unique and what is shared among such different places. Local partners facilitate access to field sites and communities, provide a grounded understanding of context, and enhance the legitimacy and local ownership of activities. In terms of practice, collaborative research can also include members with ties to local and national policy processes, concrete implementation of adaptation options on the ground, and skills in public communications, informing policy, capacity building, and community development.

Collaborative research can organize social learning and research uptake among and beyond its participants. Collaborative research is not merely a matter of collecting inputs from diverse partners but requires establishing an overall vision, coordinating how each participant contributes, and fostering norms of cooperation as an inter-organizational network. Beyond simply identifying a common theme or purpose, setting the stage for collaboration requires setting an overall vision, making choices, and brokering consensus regarding research design. These functions

required careful attention to management and distributed leadership, as well as ongoing processes to establish and update roles and responsibilities to ensure that collaborative research is an equitable partnership for all concerned. Beyond research planning, collaborative research is aided by creating spaces for diverse partners to come together, including a virtual knowledge portal and working groups around common work packages.

Africa's hotspots are at the frontline of a changing climate and offer insights on the continent's future. Given the urgency of climate action over the next decade, collaborative research must aspire to influence changes in policy, practice, behavior, and attitudes. Uptake of adaptation research by stakeholders requires access to, and facilitated opportunities to engage with, quality evidence. Collaborative research can seek to inform and accompany the implementation of local and national adaptation while also contributing to global policy discussions and fundamental understanding of climate science. Yet ultimately collaborative research requires attention to interpersonal trust, mutual respect, and leadership styles, as well as partnership agreements, power asymmetries between partners, and institutional values and cultures (Cundill et al. 2019). Research uptake requires sustained relationships with stakeholders, combining clarity on desired outcomes with a flexible and iterative approach, novel multimedia communication and branding, as well as dedicated and trained personnel (Prakash et al. 2019) (These authors provide guidance on how to make research more impactful through an open, online course: <https://www.coursera.org/learn/research-for-impact>). Pursuing research uptake requires tailoring to the specific nature of the research available, the characteristics of the stakeholders, and specific decision-making processes involved.

Conclusion

This chapter addressed three fundamental questions underpinning the resilience of people adapting to a changing climate, based on findings from collaborative research comparing hotspots across Africa (Table 1).

The first question concerns the different local climate impacts expected under 1.5 °C and 2 °C of global average warming. In 2015, there was limited information on what difference half a degree might make and how these temperature increments would affect parts of Africa. We now know that Africa's hotspots are warming faster than the global average, leading to longer heat waves, hotter days, and more intense rainfall. The local climate impacts are notable under 1.5 °C of global average warming, and more pronounced at 2 °C of global average warming. Inland deltas, rivers, dams, and groundwater are all adversely affected, with declining groundwater and reduced water availability for adjacent geographies. Heat stress and constrained water supply limit agricultural and livestock productivity. Parts of Africa are expected to surpass the 1.5 °C limit before 2030, highlighting the urgent need for local adaptation strategies and action.

The second question concerns how gender and social difference shape who is vulnerable to climate change. Understanding how vulnerability is gendered, moves

Table 1 Key messages regarding Africa's climate hotspots

What is the difference between 1.5 and 2 ° of global warming?	Many parts of Africa, especially semi-arid lands, are changing faster than the global average with near-term consequences for agriculture, energy, and water
How do gender and social difference shape who is vulnerable to climate change?	People's experience of climate change, and their ability to adapt to it, depends on age, gender, class, wealth, and ethnicity. Where someone lives also shapes their exposure, while the decision to migrate can diversify risk and alter household dynamics
What is the effectiveness of adaptation in the lived experience of people and communities?	Beyond government-led plans, a substantial amount of adaptation happens autonomously as individuals, households, companies, and private actors address the climate risks that affect them, their livelihoods, and their supply chains
How to foster collaborative research across hotspots?	Tackle regional-scale challenges by bringing together diverse partners that collectively bridge science, geography, and practice. Organize social learning and research uptake to catalyze change in policy, behavior, and attitudes

beyond stereotypes of women as powerless victims of climate change, or simple comparison between the experiences of men and women. The agency of individuals and households is affected not just by the individual characteristics such as age, ethnicity, class, and marital status but by social systems and structures. Women's and men's adaptation choices are influenced by their status and assets, what makes them unique, as well as their standing within the society. Diversification is an important household coping strategy, with gender norms shaping the possibilities open to men and women within households and communities. As climate change pushes both women and men into new roles and spaces, it is fostering new forms of cooperation and challenging traditional views on who is responsible for providing care, earning income, and managing assets.

As climate change erodes the productive potential of rural livelihoods, or endangers families where they live, those who can may choose to move elsewhere. As different family members pursue opportunities, "households" are better understood as social networks with nodes in multiple locations rather than merely cohabiting in a single-family home. Yet more than 90% of migrants from Africa's climate hotspots remain on the continent, demanding a more nuanced understanding of the circumstances under which migration offers a better life for those who move, as well as for those who remain behind. Future work needs to probe how climate stresses play out in society and why some people adapt while others do not. Moving forward, research needs to examine how slow and rapid onset impacts intermingle with climate-reliant livelihoods, combining environmental and economic reasons for why and where people decide to live, and how people respond to a changing climate.

The third question concerns the effectiveness of adaptation from the viewpoint of the lived experience of people and communities. Adaptation is an ongoing process of

continued adjustment, and people must be empowered to define success in terms that are most meaningful to them. Barriers are factors that make it harder to achieve adaptation outcomes, while enablers are those that make it easier. What matters is not so much the overall gap in adaptation efforts but a deeper understanding of what encourages or prevents effective, widespread, and sustained adaptation that aligns with the aspirations of local communities. Deficiency in information and lack of economic security are common barriers to undertaking adaptation. Decision-making at the local scale tends to rely on climate information over the daily to seasonal timescales, in formats that are readily understood and acted upon by farmers, pastoralists, and subnational governments. Longer-term climate projections, at the multiannual to decadal timescale, have been less readily accessible and are ill-suited to the real-world needs of these users.

Probing such barriers requires going beyond engineering approaches to adaptation and embracing, for example, participatory methods based on input from local inhabitants. People-centered bottom-up processes provide critical and practical information to inform adaptation and decision-making. The private sector has a vital role in determining whether societies become resilient to climate change. While semi-arid lands and marginal environments are often seen as problem landscapes and places of despair, targeted adaptation action by the private sector views them as productive landscapes and places of potential. With the right investments and policy supports, climate-vulnerable sectors become economic assets that drive transformation toward greater resilience.

Collaborative research tackles regional-scale challenges by bringing together diverse partners that collectively bridge science, geography, and practice. It can organize social learning and research uptake to catalyze change in policy, behavior, and attitudes. This is the level of ambition needed now for the decisive decade ahead of 2030, with the urgency of climate change recognized by the international community. Enhancing the ambition of climate action requires transforming our societies in a manner that leaves no one behind. Moving forward, research must respond to demands from practitioners and decision-makers: be designed to help accelerate the use of existing knowledge that informs climate action now and to fill critical gaps by generating knowledge that informs future action.

References

- Appeaning Addo K, Jayson-Quashigah P, Codjoe SNA et al (2018) Drone as a tool for coastal flood monitoring in the Volta Delta, Ghana. *Geoenviron Disasters* 5:17. <https://doi.org/10.1186/s40677-018-0108-2>
- Atela J, Gannon KE, Crick F (2018) Climate change adaptation among female-led micro, small and medium enterprises in semi-arid areas: a case study from Kenya. In: Leal FW (ed) *Handbook of climate change resilience*. Springer, Cham. https://doi.org/10.1007/978-3-319-71025-9_97-1
- Bedelian C, Moiko S, Said MY (2019) The Kenya southern rangelands beef value chain. Kenya Markets Trust, Nairobi. <https://www.kenyamarkets.org/livestock-research-the-kenya-southern-rangelands-beef-value-chain/>. Accessed 14 Dec 2020

- Brown S, Nicholls RJ, Lázár AN et al (2018) What are the implications of sea-level rise for a 1.5, 2 and 3 °C rise in global mean temperatures in the Ganges-Brahmaputra-Meghna and other vulnerable deltas? *Reg Environ Chang* 18:1829–1842. <https://doi.org/10.1007/s10113-018-1311-0>
- Carabine E, Simonet C (2018) Value chain analysis for resilience in drylands. VC-ARID synthesis report. Overseas Development Institute, London. <https://www.odi.org/sites/odi.org.uk/files/resource-documents/12517.pdf>. Accessed 1 Mar 2020
- Cochrane L, Cundill G, Ludi E et al (2017) A reflection on collaborative adaptation research in Africa and Asia. *Reg Environ Chang* 17(5):1553–1561. <https://doi.org/10.1007/s10113-017-1140-6>
- Codjoe SNA, Addo KA, Tagoe CA et al (2020) The Volta Delta, Ghana: challenges in an African setting. In: Nicholls R, Adger W, Hutton C, Hanson S (eds) *Deltas in the Anthropocene*. Palgrave Macmillan, Cham, pp 79–102
- Conway D, Nicholls RJ, Brown S et al (2019) The need for bottom-up assessments of climate risks and adaptation in climate-sensitive regions. *Nat Clim Chang* 9:503–511. <https://doi.org/10.1038/s41558-019-0502-0>
- Crick F, Gannon KE, Diop M, Sow M (2018a) Enabling private sector adaptation to climate change in sub-Saharan Africa. *Wiley Interdiscip Rev Clim Chang* 9(2):e505. <https://doi.org/10.1002/wcc.505>
- Crick F, Eskander SMSU, Fankhauser S, Diop M (2018b) How do African SMEs respond to climate risks? Evidence from Kenya and Senegal. *World Dev* 108:157–168. <https://doi.org/10.1016/j.worlddev.2018.03.015>
- Cundill G, Harvey B, Tebboth M et al (2019) Large-scale transdisciplinary collaboration for adaptation research: challenges and insights. *Global Chall* 3(4):1700132. <https://doi.org/10.1002/gch2.201700132>
- Davies JE, Singh C, Tebboth M et al (2018) Conducting life history interviews: a how-to guide. University of Cape Town. <http://hdl.handle.net/10625/58642>. Accessed 19 Mar 2020
- Davies JE, Spear D, Ziervogal et al (2020) Avenues of understanding: mapping the intersecting barriers to adaptation in Namibia. *Clim Dev* 12(3):268–280. <https://doi.org/10.1080/17565529.2019.1613952>
- de Campos RS, Codjoe SNA, Adger WN et al (2020) Where people live and move in deltas. In: Nicholls RJ, Adger WN, Hutton CW, Hanson SE (eds) *Deltas in the anthropocene*. Palgrave Macmillan, Cham, pp 153–177
- De Souza K, Kituyi E, Harvey B et al (2015) Vulnerability to climate change in three hot spots in Africa and Asia: key issues for policy-relevant adaptation and resilience-building research. *Reg Environ Chang* 15:747–753. <https://doi.org/10.1007/s10113-015-0755-8>
- Dilling L, Prakash A, Zommers Z et al (2019) Is adaptation success a flawed concept? *Nat Clim Chang* 9:572–574. <https://doi.org/10.1038/s41558-019-0539-0>
- Dupar M (2019) IPCC’s special report on climate change and land: What’s in it for Africa? Climate and Development Knowledge Network, Cape Town. <http://cdkn.org>. Accessed 13 Sept 2020
- Few R, Singh C, Spear D et al (2018) When adaptation barriers and enablers intersect: key considerations for adaptation planning drawn from ASSAR’s findings. University of Cape Town <http://hdl.handle.net/10625/58629> Accessed 8 Mar 2020
- Gannon K, Crick F, Atela J et al (2020) Private adaptation in semi-arid lands: a tailored approach to ‘leave no one behind’. *Glob Sustain* 3:e6. <https://doi.org/10.1017/sus.2019.26>
- Gonsalves A (2014) Lessons learned on consortium-based research in climate change and development. CARIAA working paper. International Development Research Centre, Ottawa <http://hdl.handle.net/10625/52501>. Accessed 16 Mar 2020
- IPCC (2018) Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty Available at <https://www.ipcc.ch/sr15/>

- Jobbins G, Ludi E, Calderone M, Sisodia R (2018) 'Leaving no one behind' through enabling climate resilient economic development in dryland regions. Overseas Development Institute, London. <http://hdl.handle.net/10625/59290>
- Jones L, Harvey B, Cochrane L et al (2018) Designing the next generation of climate adaptation research for development. *Reg Environ Chang* 18(1):297–304. <https://doi.org/10.1007/s10113-017-1254-x>
- Lafontaine A, Volonté C, Pionetti C, Moreno C (2018) Collaborative adaptation research initiative in Africa and Asia: summative evaluation. Groupe-conseil baastel ltée, Gatineau. <http://hdl.handle.net/10625/57296>. Accessed 17 Mar 2020
- Maharjan A, de Campos RS, Singh C et al (2020) Migration and household adaptation in climate-sensitive hotspots in South Asia. *Curr Clim Change Rep* 6:1–16. <https://doi.org/10.1007/s40641-020-00153-z>
- New M, Bouwer R, Bosworth B et al (2019) Global warming of 1.5°C and higher brings profound challenges to semi-arid regions: an ASSAR cross-regional insight. University of Cape Town. <http://www.assar.uct.ac.za/theme-1-point-5-degree>. Accessed 14 Mar 2020
- Nkemelang T, New N, Zaroug M (2018) Temperature and precipitation extremes under current, 1.5 °C and 2.0 °C global warming above pre-industrial levels over Botswana, and implications for climate change vulnerability. *Environ Res Lett* 13:065016. <https://doi.org/10.1088/1748-9326/aac2f8>
- O'Neill M (2020). Collaborating for adaptation: findings and outcomes of a research initiative across Africa and Asia. International Development Research Centre, Ottawa. <http://hdl.handle.net/10625/58971>. Accessed 10 July 2020
- Ofoegbu C, New M, Nyamwanza AM et al (2020) Understanding the current state of collaboration in the production and dissemination of adaptation knowledge in Namibia. *Environ Dev Sustain* 22:1017–1037. <https://doi.org/10.1007/s10668-018-0231-y>
- Prakash A, Cundill G, Scodanibbio L et al (2019) Climate change adaptation research for impact. CARIAA working paper. International Development Research Centre, Ottawa <http://hdl.handle.net/10625/57489>. Accessed 17 Mar 2020
- Qaisrani A, Salik KM (2018) The road to climate resilience: migration as an adaptation strategy. Sustainable Development Policy Institute, Islamabad. <http://hdl.handle.net/10625/58563>. Accessed 19 Mar 2020
- Rao N, Lawson ET, Raditloaneng WN et al (2019a) Gendered vulnerabilities to climate change: insights from the semi-arid regions of Africa and Asia. *Clim Dev* 11(1):14–26. <https://doi.org/10.1080/17565529.2017.1372266>
- Rao N, Mishra A, Prakash A et al (2019b) A qualitative comparative analysis of women's agency and adaptive capacity in climate change hotspots in Asia and Africa. *Nat Clim Chang* 9:964–971. <https://doi.org/10.1038/s41558-019-0638-y>
- Rao N, Singh C, Solomon D et al (2020) Managing risk, changing aspirations and household dynamics: implications for wellbeing and adaptation in semi-arid Africa and India. *World Dev* 125:104667. <https://doi.org/10.1016/j.worlddev.2019.104667>
- Rigaud KK, de Sherbinin A, Jones B et al (2018) Groundswell: preparing for internal climate migration. World Bank Group, Washington, DC. <http://hdl.handle.net/10986/29461>
- Scodanibbio L, Morchain D (2019) Adaptation is about people. Climate and Development Knowledge Network, Cape Town. https://cdkn.org/2019/09/feature-adaptation-is-about-people/?loclang=en_gb. Accessed 1 Apr 2020
- Singh C (2019) Migration as a driver of changing household structure: implications for local livelihoods and adaptation. *Migr Dev* 8(3):301–319. <https://doi.org/10.1080/21632324.2019.1589073>
- Singh C, Basu R (2019) Moving in and out of vulnerability: interrogating migration as an adaptation strategy along a rural urban continuum in India. *Geogr J* 186(1):87–102. <https://doi.org/10.1111/geoj.12328>

- Singh C, Daron J, Bazaz A et al (2018) The utility of weather and climate information for adaptation decision-making: current uses and future prospects in Africa and India. *Clim Dev* 10(5):389–405. <https://doi.org/10.1080/17565529.2017.1318744>
- Singh C, Tebboth M, Spear D et al (2019) Exploring methodological approaches to assess climate change vulnerability and adaptation: reflections from using life history approaches. *Reg Environ Chang* 19:2667–2682. <https://doi.org/10.1007/s10113-019-01562-z>
- Tompkins EL, Vincent K, Nicholls RJ, Suckall N (2018) Documenting the state of adaptation for the global stocktake of the Paris Agreement. *Wiley Interdiscip Rev Clim Chang* 9(5):e505. <https://doi.org/10.1002/wcc.545>
- Toure A, Diekkrüger B, Mariko A, Cissé AS (2017) Assessment of groundwater resources in the context of climate change and population growth: case of the Klela Basin in Southern Mali. *Climate* 5(3):45. <https://doi.org/10.3390/cli5030045>
- UNFCCC (2015) The Paris Agreement. https://unfccc.int/sites/default/files/english_paris_agreement.pdf
- WMO (2019) The global climate in 2015–2019. World Meteorological Organization WMO, Geneva. https://library.wmo.int/doc_num.php?explnum_id=9936