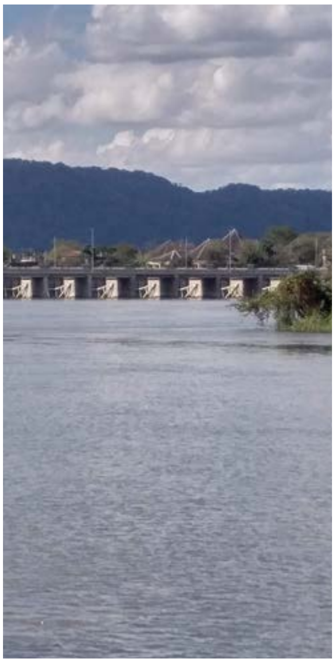
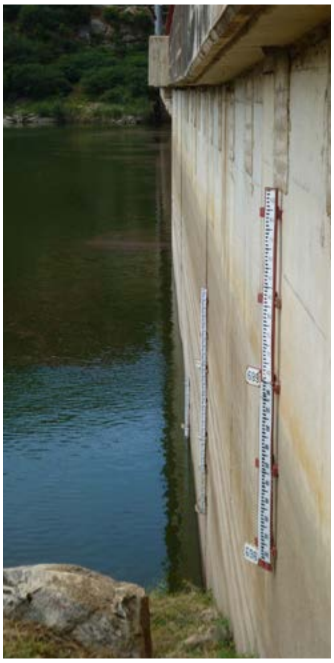
FUTURE CLIMATE FOR AFRICA

UMFULA BRIEF

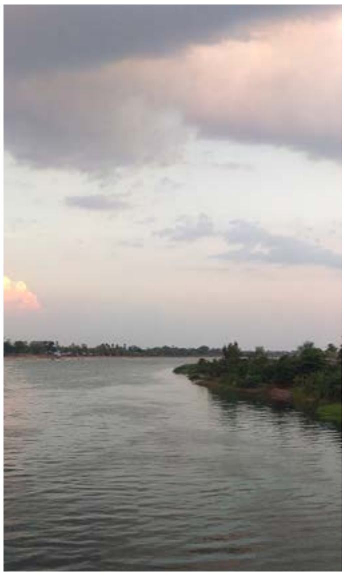
October 2019

The current and future climate of central and southern Africa

What we have learnt and what it means for decision-making in Malawi and Tanzania



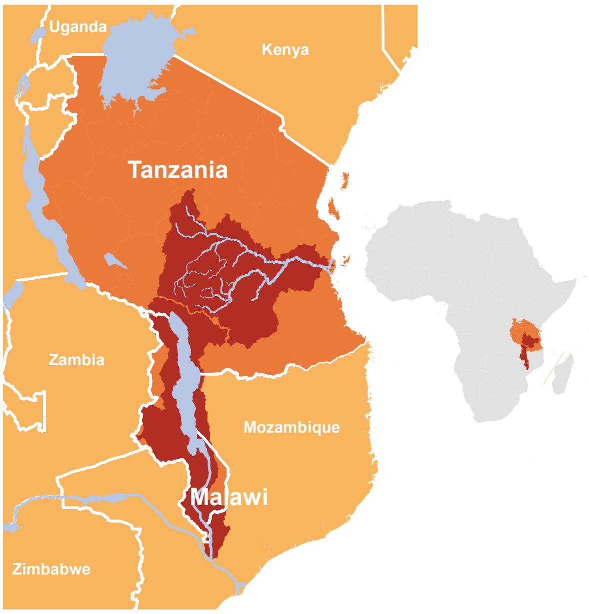


ABOUT THE FUTURE CLIMATE FOR AFRICA PROGRAMME AND THE UMFULA PROJECT

Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science can inform management of future climate risks and has an impact on human development across the continent. The programme is funded by the UK's Department for International Development (DfID) and Natural Environment Research Council (NERC) and is implemented by five consortia and a Coordination, Capacity and Knowledge Exchange Unit (CCKE).

UMFULA (Uncertainty Reduction in Models for Understanding Development Applications) is one of the consortia, looking at central and southern Africa, with case studies in Malawi and Tanzania focusing on managing water with increasing demands for agricultural production and hydropower (the so-called water–energy–food nexus) under a changing climate.

UMFULA has taken an interdisciplinary approach and has collaborated extensively with key government agencies in Malawi and Tanzania to design climate information relevant for decision-making. In Malawi, our engagement has been led by Lilongwe University of Agriculture and Natural Resources and the Malawi University of Science and Technology, and in Tanzania by Sokoine University of Agriculture.



UMFULA case studies in Malawi and Tanzania, highlighted in dark red

Among those involved in Malawi are the Department of Climate Change and Meteorological Services (DCCMS), the Ministry of Agriculture, Irrigation and Water Development (Departments of Irrigation, Surface Water, and Agriculture Extension Services), the Department of National Parks and Wildlife, the Electricity Supply Corporation of Malawi Ltd. (ESCOM), the Electricity Generation Company Ltd. (EGENCO), the Shire River Basin Management Programme (SRBMP) and operators of the Kamuzu Barrage.

In Tanzania, key stakeholders include the Rufiji Basin Water Board (RBWB), the Tanzania Electricity Supply Company (TANESCO), the Ministry of Water and the Tanzania Meteorological Agency (TMA).

The UMFULA team is immensely grateful to these organisations for engaging with us, and we hope that our research will support their planning for climate change.

FUTURE CLIMATE FOR AFRICA

CONTENTS

Ifunda wetland converted into maize fields, Rufiji, Tanzania, 2018

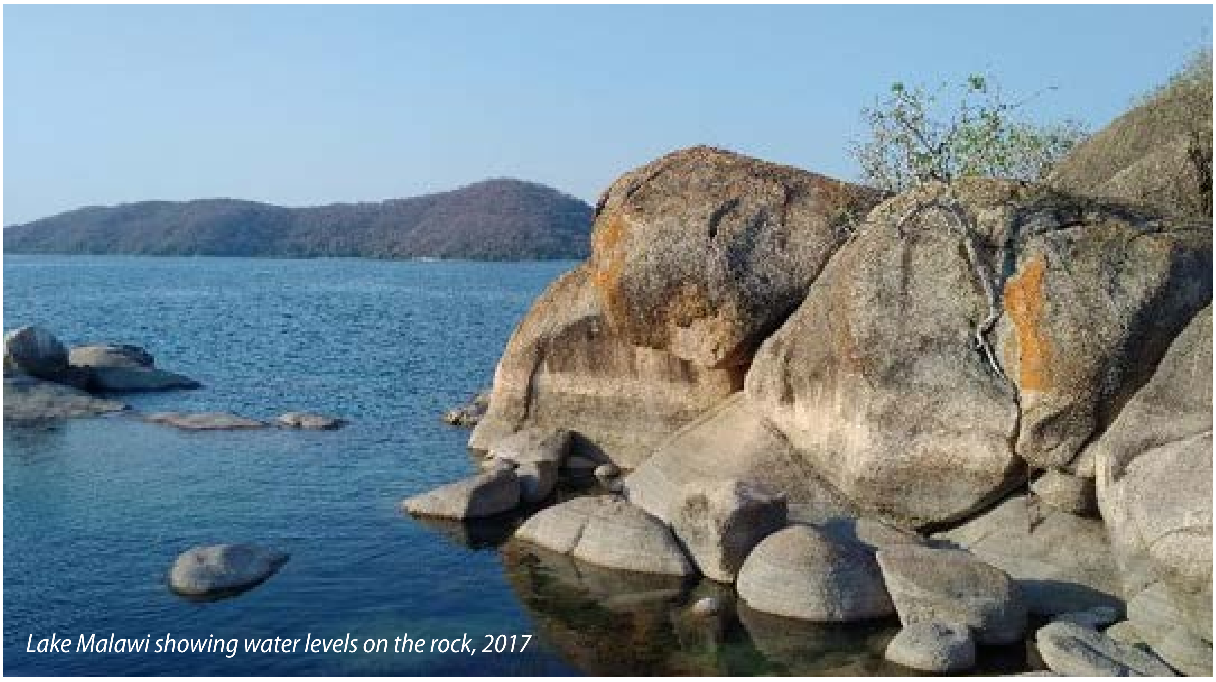
SUMMARY

UMFULA has addressed questions of climate science, climate impacts and decision-making processes for adaptation, including:

- How does the climate of central and southern Africa work? And how well do climate models represent the key processes responsible for climate?
- How might the climate of central and southern Africa change in future decades out to ~2050 and how sure are we about the projected changes?
- To what extent can decision-making approaches incorporate climate change uncertainties within investment decisions that cut across the water, energy and food sectors?
- How does the political and institutional environment influence the usefulness and usability of climate information for adaptive decision-making?

Our results show:

- Understanding the likely future characteristics of climate risk is a key component of adaptation and climate-resilient planning, but given future uncertainty it is important to design approaches that are strongly informed by local considerations and are robust to uncertainty, i.e. options that work reasonably well across a range of uncertain future climate (and other) conditions.
- Choosing the right tools and approach for climate risk assessment and adaptation to suit the scale of the decision allows a suitable trade-off between robustness and resources required (time and expertise) for analysis.
- In the medium term, policy decisions require careful cross-sectoral planning, particularly in cases involving large investments, long life-times and irreversibility, where there is a strong argument for assessing resilience to future climate change (for example around water, energy and food in Malawi and Tanzania).
- The process of co-production of knowledge by researchers and wider stakeholders contributes to building societal and institutional capacity to factor climate risks into long-term planning. It also builds the capacity of researchers to better understand real world decision contexts in which climate change is one of many important factors.

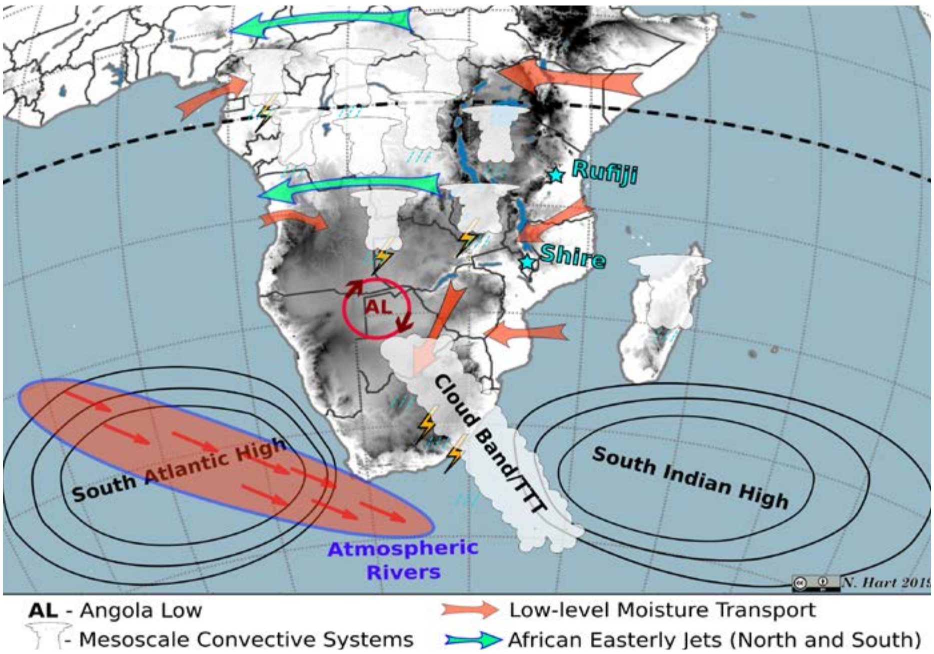


Lake Malawi showing water levels on the rock, 2017

IMPROVEMENTS IN THE UNDERSTANDING OF RAINFALL REGIMES IN CENTRAL AND SOUTHERN AFRICA

UMFULA research has generated key advances in the understanding of the varied processes and features of central and southern Africa's climate system (Figure 1). With better understanding of the key features of the circulation we can analyse the mechanisms by which climate models simulate the climate system in order to evaluate the credibility of the modelled future climate. This approach is in contrast to more dated approaches whereby model output is simply statistically summarised. We focus on rainfall as the most important challenge for models and the most important variable for the water–energy–food nexus.

Figure 1: Central and southern Africa's climate is characterised by a range of features and processes that the UMFULA team has studied to advance understanding of the climate system. (Source: Neil Hart)



Cloud bands

Cloud bands are important because they give rise to widespread rainfall and are responsible for a significant proportion of extreme events. We have improved understanding of the ways in which the El Niño Southern Oscillation (ENSO) circulation system affects rain over southern Africa, in particular the relationship with cloud bands (Hart et al., 2018; see Figure 1). We have found that 150–200% more cloud bands develop during La Niña seasons. During El Niño events fewer cloud bands develop over southern Africa, while they are 150% more likely over the Indian Ocean to the east of Madagascar.

Extreme events: Cape Town's drought

During the lifetime of the UMFULA project, Cape Town experienced a severe drought which forced the city's industrial sector and residents to implement significant demand management to avoid running out of water in 2018, commonly referred to as "day zero". One key feature of the drought was the competition between urban settlements and agricultural sector water demand – a tradeoff that ultimately featured prominently in both city and provincial response (Archer et al., 2019).

We found a relationship between poleward shifts in the South Atlantic Anticyclone and moisture corridors during 2015–17 and the Cape Town drought (Sousa et al., 2018). Changes in the frontal systems in the South Atlantic that bring the winter rainfall to Cape Town – in terms of how often they occur, where they occur, and how they move over time – can also be linked to the recent dry conditions (Burls et al., 2019). It is likely that such dry conditions will become a more regular occurrence in the future, particularly during the early winter months, but also with a possibility of more frequent dry spells during the winter rainfall season (Mahlalela et al., 2018).

Conditions in the South Atlantic Ocean also play a role in determining when there is high rainfall. In the last three decades, atmospheric rivers (ARs) (long and narrow regions in the atmosphere transporting water vapour) across the South Atlantic were responsible for eight of the top nine rainfall events in the Western Cape region of South Africa (Blamey et al., 2018). The moisture that leads to these ARs contributing to Western Cape rainfall can be traced all the way back to the Amazon region in South America (Ramos et al., 2019).

Regional circulation features: the Angola Low and South Indian Ocean high pressure systems

We have investigated a previously under-studied regional circulation feature that forms during the summer season – the Angola Low – which is crucial to the southern African region (see Figure 1). We have evaluated how the feature develops through the season (Munday and Washington, 2016; Howard and Washington, 2018) and why it tends to be semi-stationary over southern Africa (Howard and Washington, 2018). Models that are excessively wet tend to simulate an Angola Low that is too intense.

We have also established how features of the regional circulation, such as the Angola Low and the South Indian Ocean High pressure systems, interact with El Niño events to modify rainfall amounts over southern Africa (Howard and Washington, 2019). El Niño events do not all influence southern African climate in the same way. The 2015–16 drought over southern Africa was the most extreme on historical record, and associated with El Niño, while during the equally strong 1997/98 El Niño event normal rainfall levels occurred. The difference between the events has been traced to the intensity of the Angola Low (Blamey et al., 2018).

The Congo Basin

The Congo Basin in central Africa is a critical driver of the global tropical atmospheric circulation. However, very little is known about the Congo Basin and the viability of its extensive tropical rainforests in a warmer world. Using climate models, we have assessed the key moisture transport pathways into the central Africa region and established how the strength of this moisture transport modulates models that are wetter over the basin compared with those that are drier (Creese and Washington, 2016; 2018).

ASSESSING CONFIDENCE IN MODEL SIMULATION OF CLIMATE

An understanding of the key features of the climate, and how they work, is critical in order to be able to effectively model climate and have confidence in projected future climates. UMFULA has advanced an existing challenge – the ability of models to capture these key features that drive the climate in central and southern Africa.

More accurate simulation of cloud bands with convection-permitting models

Correctly simulating the seasonal cycle of cloud bands is a challenge for climate models as it requires adequate representation of sub-daily subtropical convection and the subtropical upper level wind stream over southern Africa (Hart et al., 2018). We have identified that the simulated annual cycle of cloud bands in models is generally too flat without the dominant summertime peak that we see in reality, but that the simulation improves markedly in a very high resolution climate model which simulates convection more directly (Hart et al., 2018). Convection-permitting models thus have the potential to more accurately represent African rainfall patterns.

Why models simulate too much rainfall in southern Africa

We have also identified two reasons that models simulate too much rainfall in southern Africa. Models with a stronger Angola Low simulated enhanced northerly moisture transport and an increased rate of moisture convergence over the interior of southern Africa (Munday and Washington, 2016). Another reason is that of an excessive flux of water vapour from the Indian Ocean. This arises because models do not accurately capture the role of topography in limiting the supply of moisture (Munday and Washington, 2018; Barimalala et al., 2018).

Projections of rainfall change in central Africa

Over central Africa, we found that models that historically project more rainfall import more water vapour from surrounding oceans (e.g. Creese and Washington, 2016; 2018). We question the driest rainfall change signals during the rainy season in the east Congo Basin as the models that historically project less rainfall fail to capture the vertical structure of the African Easterly Jet, which is a strong wind around 5km above ground over northern and southern central Africa (Creese et al, 2019). The largest change in rainfall over central Africa occurs in the December to February dry season when models simulate drying. Confidence in this projected drying remains low because the range of average rainfall from the driest to the wettest models is very large compared with the small amount of change. Furthermore, the drying in central Africa is associated with remote connections to the rainfall system over the tropical west Pacific and we have a limited understanding of this connection.


Sisal plantation, Morogoro, Tanzania, 2018

The first Lidar system to study winds in central Africa

Evaluating climate models requires observational data. This is, however, lacking over much of central Africa where there have historically been few weather stations. To address this absence, a Lidar instrument has been deployed in Cameroon as part of the UMFULA project. We believe it is the first Lidar installed in central Africa to study winds. The Lidar, an automatic weather station recording high time resolution parameters, including surface temperature and rainfall and daily measurement of temperature, humidity and pressure through the depth of the atmosphere from weather balloons, will, we hope, provide new insights about the dynamics of the region.

A Lidar is a remote-sensing instrument which is able to retrieve profiles of three-dimensional wind by detecting the back scattering of a laser beam emitted by the instrument. The beam is scattered off small aerosol particles. Movement of the particles by the ambient wind introduces a Doppler shift in the emitted beam frequency. That shift can be traced to the particle movement and hence wind speed and direction recovered by the instrument. Since the time taken for the beam to be returned to the instrument is measured, the height of the wind responsible for causing the Doppler shift can also be calculated. It was configured to record wind profiles every 15 minutes. Up to September 2019, more than 26,000 wind profiles, many to a height of 3 or 4km, have been recorded.

The Lidar in Cameroon, 2019

Effects of the El Niño Southern Oscillation on southern African circulation patterns

The El Niño Southern Oscillation (ENSO) is the single biggest control on rainfall in Southern Africa, but the link is complex. Our improved insights into the ENSO show how a strong Pacific El Niño event affects regional circulation patterns in southern Africa. This linkage of African climate with a phenomenon that takes place on the other side of the globe (known as a teleconnection) highlights one challenge that coupled atmosphere–ocean models face in effectively simulating the effect of ENSO on African climate (Blamey et al., 2018). We also noted that human-caused warming results in increased risk of high intensity drought events – of the intensity experienced over southern Africa in 2015–16 related to the major El Niño event (Kolusu et al., 2019).

Projections of climate change in southern Africa

Early summer drying over southern Africa is one of two large land-based climate change rainfall signals regarded by the Intergovernmental Panel on Climate Change (IPCC) (2014) as robust. We have confidence that extreme drying is unlikely (e.g. Munday and Washington 2017; 2018; 2019), because the extreme drying occurs in climate models that simulate far too much rainfall in the current period. These models dry out in the future to a climate regime that is very similar to current climate. However, models with a current rainfall regime that is more realistic simulate drying, but not extreme drying.

Tailored future climate information for the tea sector in Malawi

Tea is a key sector for both the economy and livelihoods of people in Malawi. It is the country's second largest export commodity and largest private sector employer. However, the amount of tea produced and the quality of crop are contingent upon rainfall and temperature. Climate change thus poses a potential risk to the sector.

In particular the tea crop is sensitive to changes in temperature. Heat stress is more prominent across the tea growing regions during the dry season (May to November), leading to increased incidences of leaf sun-scorch, especially for susceptible cultivars. Based on insights from large tea estates and smallholder farmers in Mulanje and Thyolo districts, and the Tea Research Foundation of Central Africa, we have tailored future climate projections using station observations, CMIP-5 models and the new convection-permitting pan-African climate model (CP4 Africa) simulation.

Moving beyond understanding the mean changes in future rainfall and temperature that models typically project, we analysed changes for a set of tea-specific metrics for dry and wet seasons that could affect tea yield or quality such as heat stress and dry spells (Vincent et al., submitted). Co-producing such tailored information enables the tea sector to identify appropriate adaptation options to reduce climate risk.

Climate change adaptation prioritisation workshop with smallholder farmers, 2018

Tea plantation under irrigation, Malawi, 2018

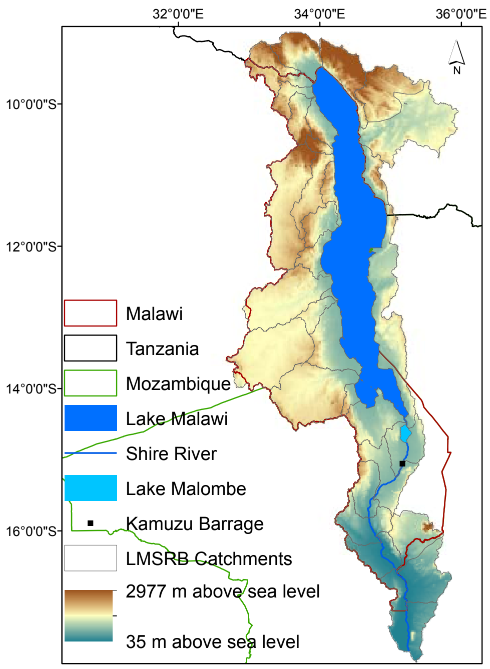
WHY INCORPORATING UNCERTAINTY INTO DECISION-MAKING APPROACHES IS ESSENTIAL FOR ADAPTATION PLANNING IN MALAWI AND TANZANIA

Malawi and Tanzania were the case study countries adopted by the UMFULA project. While these two countries are representative of the Southern African Development Community (SADC) region in terms of threats posed by climate change to development trajectories, their geographical location, between major climate systems, makes it difficult to confidently project future rainfall conditions. This is because the response in the case study area depends on how the climate of the key regions (southern Africa, eastern Africa and central Africa) changes as well as how broader geographical influences change (e.g. the ENSO) – these all remain highly uncertain.

New scientific insights into the region's climate advance our understanding of drivers of variability and inform how much confidence we can place in the model projections of future climate. However, expecting that climate models will be able to generate projections with much higher confidence, as well as waiting for such outputs, is not the best approach for Malawi or Tanzania, particularly in cases where major decisions are being made now about infrastructure with long lifetimes. Instead, to make adaptive decisions that reduce climate risk, we can investigate the implications of a range of potential outcomes. This allows decision-makers to determine priorities (which could be minimising losses, or maximising potential gains, for example) while factoring in the uncertainties about future climate projections. Development plans being made in both Malawi and Tanzania (but also elsewhere in the SADC region) comprise critical trade-offs between major investment decisions in irrigation, hydropower and agricultural intensification and the impacts on ecosystem services in the affected areas, among other considerations.

Future water availability in the Lake Malawi Shire River Basin

Figure 2: Location, elevation and catchments of the Lake Malawi Shire River Basin. (Source: Bhave et al., 2019)



In Malawi, we have focused on the Lake Malawi Shire River Basin, which covers most of the country (see Figure 2). Outflows of water from Lake Malawi into the Shire River are critical to support major elements of the country's economy – in the form of hydropower and irrigation, and biodiversity – in the form of environmental flows.

Co-producing a Water Evaluation and Planning (WEAP) model

We have co-produced a Water Evaluation And Planning (WEAP) model to assess the impact of climate change on water resources, working with in-country stakeholders, including the Ministry of Agriculture, Irrigation and Water Development (Departments of Irrigation, Surface Water, and Agriculture Extension Services), the Department of National Parks and Wildlife, the Electricity Supply Corporation of Malawi Ltd. (ESCOM), the Shire River Basin Management Programme (SRBMP) and operators of the Kamuzu Barrage (the structure that regulates lake outflows). This is the first simulation-based water model to represent so many features of this unconventional lake-basin system (Bhave et al., 2019).

Projecting future water availability in the Lake Malawi Shire River Basin

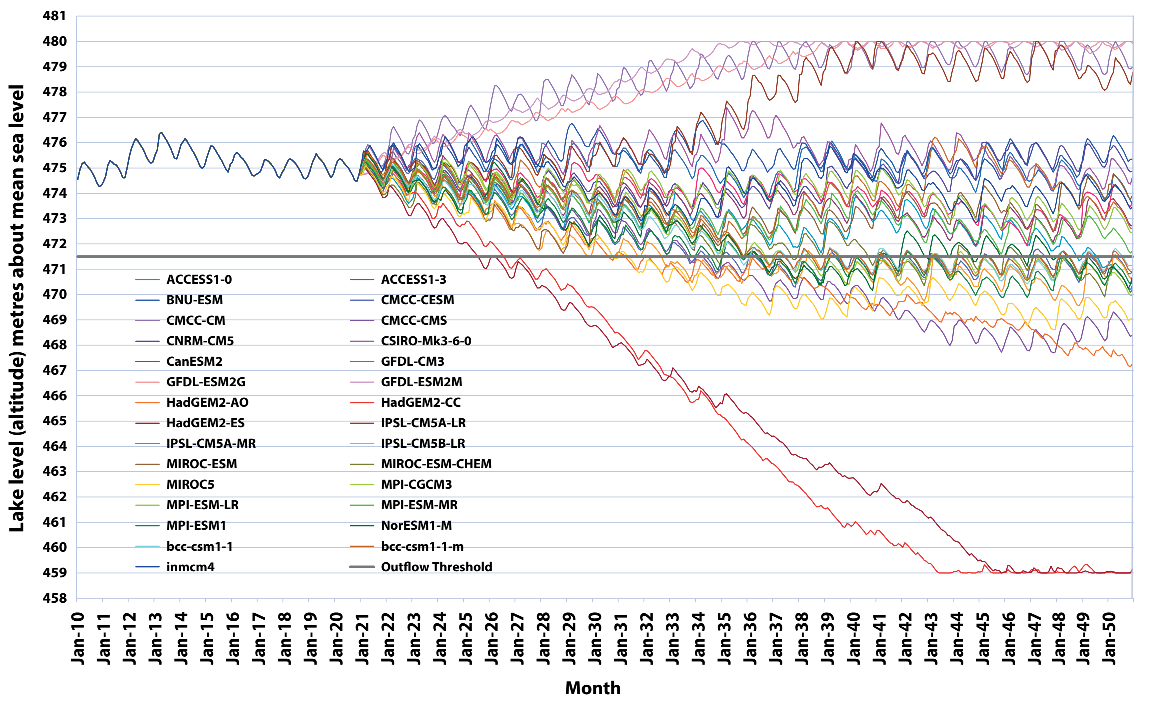
Running the WEAP model under future climate projections from 29 bias-corrected climate models based on the RCP 8.5 scenario (the IPCC scenario with the highest emissions) for the period 2021–2050 shows a range of potential future lake levels (see Figure 3).

Approximately one third of models (9 of 29) show very high lake levels leading to potentially severe downstream floods. Just over one third (11 of 29) of models show substantial decline that will lead to lake levels dropping below the Lake Malawi Outflow Threshold, which would dramatically reduce hydropower generation and irrigation water supply in the Shire River Basin. Finally, approximately one third show lake level fluctuations similar to what has been experienced in the recent past.

Robust decision-making approaches can minimise climate risk

When making planning decisions relating to water it is important to use robust approaches that will be sustainable, taking into account the full range of projected increases or decreases. We also included a focus on historical variation in lake levels to help provide a stronger resonance with Malawian decision-makers and make more tangible the possibility of extremes to then plan accordingly, for example by considering this range into the upgrading of the Kamuzu barrage.

Figure 3: Climate change impacts on Lake Malawi levels based on 29 Global Climate Model projections in the Shire River Basin. (Source: Bhave et al., 2019)



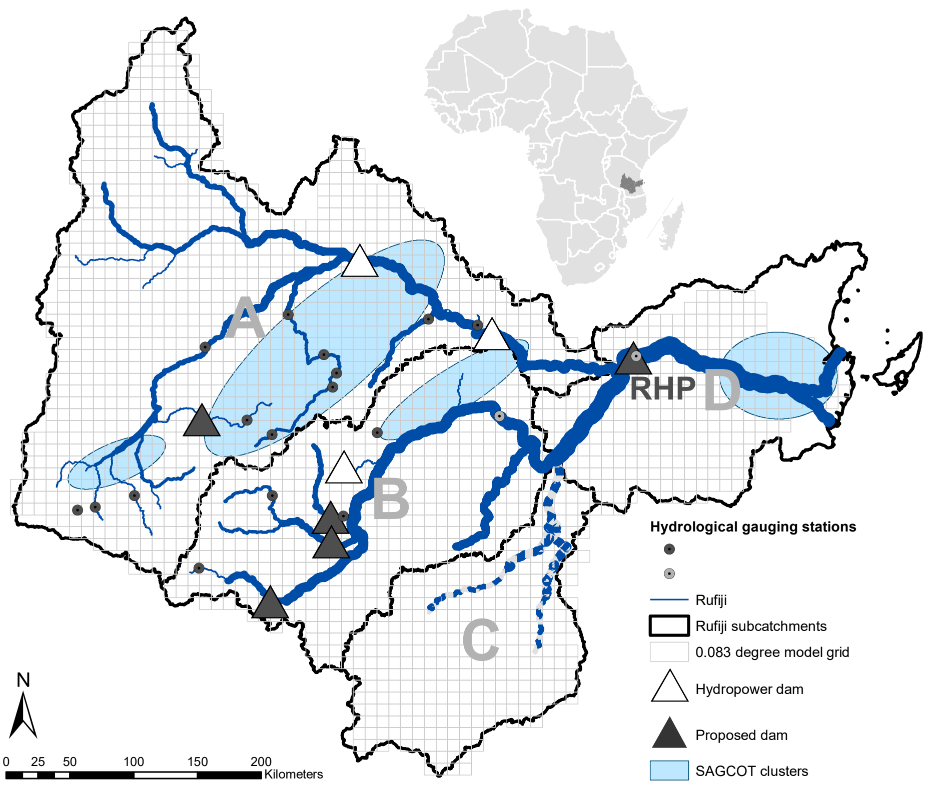
Trade-offs around water allocation in the Rufiji River Basin

In Tanzania, we focused on the Rufiji River Basin. The Rufiji produces half of Tanzania's river flow, supplying water for more than 4.5 million people, irrigation and livestock, and generating roughly 80% of the country's hydropower. The basin also includes several major wetland systems and areas of high conservation value, including formally protected areas, such as National Parks. Major intensified socio-economic development over the next two decades is being planned as part of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT) and the country has committed to produce more hydropower, in particular via the Rufiji Hydropower Project at Stiegler's Gorge, near the Rufiji Delta.

Modelling future water availability in the Rufiji River Basin

We have regionalised a well-known global hydrological crop model, improving input by calibrating the runoff and crop modules and fine-tuning reservoir characteristics to match those of the planned Rufiji Hydropower Project – with a performance good enough to support use for scenario exploration given the very limited observational data in many parts of the basin (Siderius et al., 2018; see Figure 4).

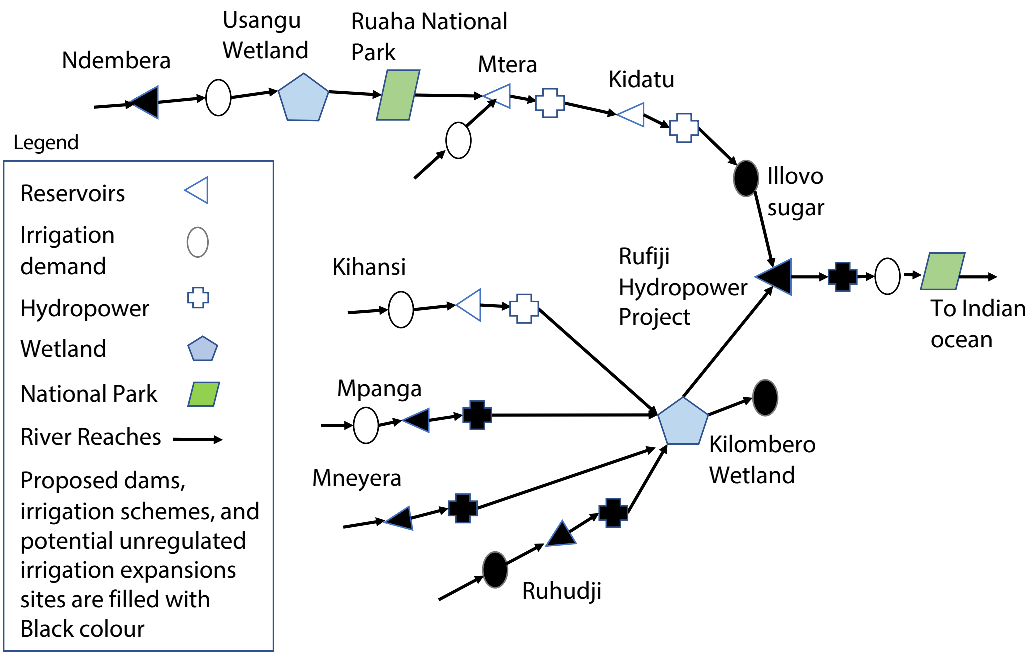
Figure 4: Hydrological model of the Rufiji system overlaid with 0.083 ° (~9 by 9km) grid and areas identified for irrigation expansion (SAGCOT clusters) (Siderius et al., 2018). RHP is Rufiji Hydropower Project. Letters refer to main tributaries: A is Great Ruaha, B is Kilombero, C is Luwegu and D is the Main Rufiji channel. (Source: Conway et al., 2019)



Running the model under future climate projections from the 32 climate models based on the RCP 8.5 scenario (the IPCC scenario with the highest emissions) for the period 2021–2050 shows a range of impacts on river flows in the Rufiji Basin, stretching from much higher flows to substantially lower flows, a situation similar to that found in Malawi.

Considering decisions about plans in the water, energy and food sectors requires coupling the hydrological system with a water resource system model that simulates the operation and effects of dams and irrigation in the basin (Conway et al., 2019; see Figure 5). We are currently doing this to support robust decision-making approaches. The decisions involve many options for combinations of new dams (and their operating rules), and new/expanded irrigation areas. Our aim is to provide an evidence base for making decisions regarding trade-offs in water use. The drier conditions projected by several models would strongly affect the functioning of reservoirs and expectations on firm energy levels.

Figure 5: Major existing and planned dams and main areas of irrigation simulated in the water resources systems model developed by UMFULA (currently 11 irrigation demand nodes, four existing reservoirs, five new reservoirs and six run-of-the-river hydropower dams). (Source: Conway et al., 2019)



Identifying trade-offs for water between agriculture, hydropower and environmental flows

Stakeholder consultation across different sectors identified management objectives for the Rufiji basin. These include maximising energy generation and its reliability, maximising irrigation water supply reliability and total irrigation area, and minimising the impact of development on river flows that provide important environmental services (e.g. habitats dependent on seasonal flooding).

An understanding of the consequences of alternative development and management options based on up-to-date evidence is vital – not only in terms of the decision to build infrastructure but also on its design and operational management. Our results show that well managed, adaptive dam operational rules will be needed to deal with variable reservoir inflows – under conditions of climate variability and change at a range of time-scales.

Socially differentiated effects of different macro-level decisions

There are also socially differentiated implications of such decisions. For example, while irrigation may benefit the large scale and aggregate production levels, it will often affect water availability for small-scale farmers whose scale of operation means developing proper irrigation infrastructure is rarely an option. This was found to be particularly the case for those farmers working in the tea and sugarcane industries, two key sectors important for both the economy and livelihoods in Malawi and Tanzania. Considering equity in adaptation decisions is therefore an important criterion (Pardoe et al., submitted).

HOW THE POLICY AND INSTITUTIONAL ENVIRONMENT AND AGENCY AFFECT WHETHER OR NOT CLIMATE INFORMATION IS USED IN DECISION-MAKING

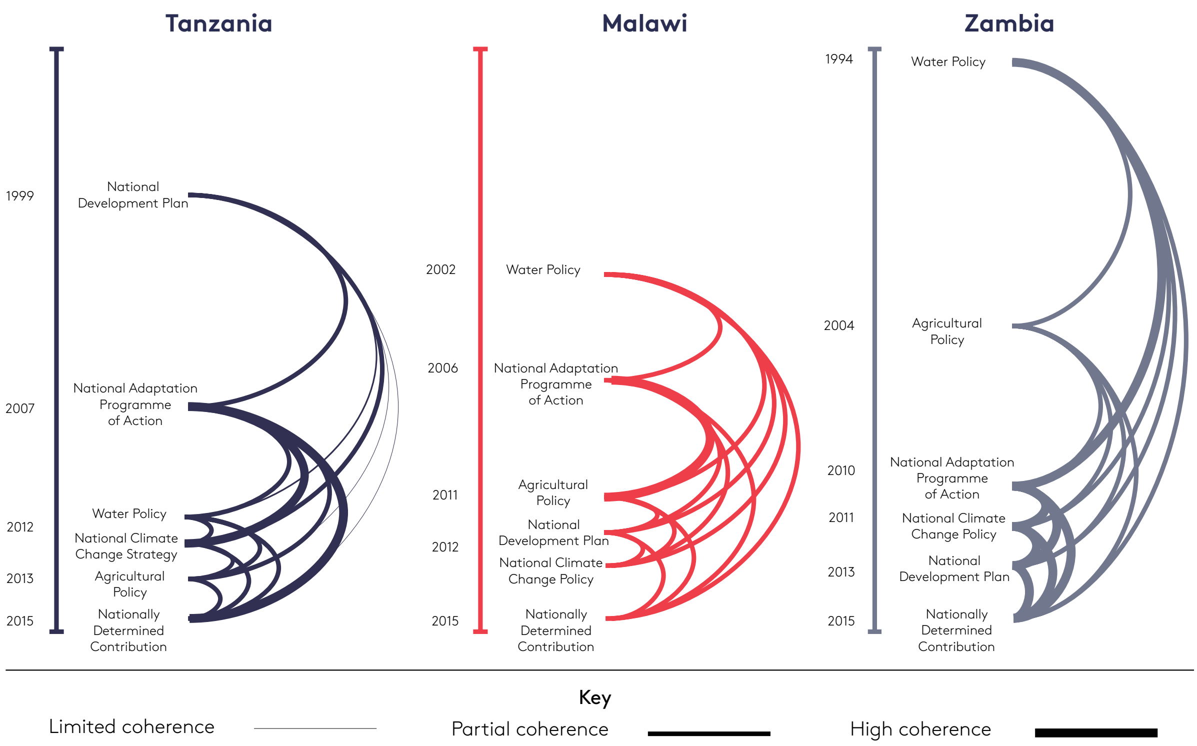
Work across Malawi, Tanzania, Zambia and southern Africa more broadly produced key insights into whether or not and how climate information can be used to inform cross-sectoral decision-making.

Political commitment to addressing climate change and achieving sustainable development in the water, energy and agriculture sectors exists within southern African countries (England et al., 2018). However, optimal efficiency in achieving adaptation is impeded by policy incoherence across sectors (see Figure 6). Ensuring coherence between policies is challenging due to inconsistency in timeframes of policy development and resource constraints that limit the frequency of policy reviews (Curran et al., 2018).

More detailed analysis of the political economy in Malawi, Tanzania and Zambia shows that ideas, power and resources converge in different ways to create institutional environments that either support or constrain the pursuit of climate change policy ambition and targets (England et al., 2018). We found that change in leadership, and the oft-concurrent cabinet reshuffles, changes in ministerial mandates and rotation of high-level civil servants, leads to a focus on short-term planning that links with electoral cycles, rather than the required focus on long-term building of resilience strategies and climate adaptation investments (Pardoe et al., submitted).

Reliance on donor funding can lead to turf wars and competition between ministries for resources (such as in Zambia) and contribute to barriers to coordination for coherent cross-sectoral approaches (such as in Malawi) (England et al., 2018).

Figure 6: Coherence and sectoral policy linkages around climate, water, energy and agriculture in Tanzania, Malawi and Zambia. (Source: Curran et al., 2018)



WHY CAREFULLY DESIGNED CAPACITY-BUILDING IS AN ESSENTIAL CONDITION FOR EFFECTIVE CLIMATE CHANGE ADAPTATION

Surveys and extensive interviews show external reliance also undermines a sense of autonomy and agency to act among staff in the ministries, even when technical capacity and individual motivation exists (Pardoe et al., 2018). They are dependent on donor-determined projects which may be selective in the aspects of climate change adaptation plans and policies they support and even divert focus away from government priorities.

Capacity-building is therefore not necessarily about running more training courses, but providing autonomy and operational budget to government staff so that they can effectively implement adaptation policy across multiple sectors (Mataya et al., submitted). In Malawi, government and development partners have been providing and funding a range of education and training initiatives. Findings indicate that long-term education and short-term training have complementary roles in influencing successful adaptation practices. Short-term training workshops are most useful when they are customised to the particular needs of participants, are participatory in design and implementation, and when they are tailored using context-specific examples. Action planning, on-the-job training and continued mentorship after training are also effective, but remain rarely used. Challenges that impede effective capacity-building relate not only to the training design and structure, but also to the inadequacy of training needs assessments and the organisational structure in which trainees attempt to put their skills and knowledge into practice.

Focusing more broadly on the SADC region, findings mirrored those from Malawi. Capacity gaps were frequently cited as either the most important obstacle, or one of the most important obstacles, to real use of climate information for improved decision-making (Lötter et al., 2018). Capacity-building efforts relying on workshops are frequently used but are not always effective. Instead, sustained engagement with focal points is frequently more productive, even though it can be more resource-intensive – in financial terms and in human capital terms.

Illovo Sugar plantation in Nchalo, Malawi, 2016

Climate information access and use among smallholder farmers

The uptake of climate information among local users relies on the information being useful, usable and used. Through two streams of research in Malawi and one in Tanzania, we have gained insight into smallholder farmers' access and use of climate information.

Smallholder sugarcane farmer in southern Malawi participating in in-depth interview, 2017

Participatory Scenario Planning (PSP) has been introduced to several districts in Malawi to bring together producers and users to co-produce interpretations of seasonal weather information. We found that although challenges – including lack of technical capacity, constrained financial resources and aforementioned weak institutional capacity – prevent optimum effectiveness of PSP, the process does have the potential to generate credible, legitimate and salient information that is both usable and being used by the receivers. Its usability is reinforced through demonstration of farmers' effective adoption of the information. Despite nationwide implementation, the numbers of recipients are, however, few and scattered (Tembo-Nhlema et al., 2019).

Smallholder sugarcane farmers in Malawi, despite being part of a large contract-farming organisation comprising nearly 800 farmers in a district where PSP has been implemented, do not benefit from the co-produced climate information. These farmers predominantly rely on the radio or neighbours to receive daily to seasonal forecasts. The research suggests that overcoming the technical, financial and institutional barriers may lead to PSP having significant impact on smallholder farmers' potential to successfully adapt to climate change and climate variability. Ensuring participation of larger co-operatives, contract farming organisations and NGOs in the PSP processes would reach a much larger group of beneficiaries, and would have a potentially significant spill-over effect among villages and communities.

In the Kilombero River catchment of Tanzania, research finds that people make important water-use and farming decisions for the upcoming year, such as season planting, based in particular on the seasonal forecasts they get from the country's national meteorological service. They receive it through the agriculture extension service officers or through broadcasts on local television and radio stations. This shows the importance of keeping regular, accurate forecast information flowing to communities on the ground.

PUTTING RESEARCH INTO PRACTICE: HOW UMFULA CO-PRODUCED AND COMMUNICATED FINDINGS FOR IMPACT

Working together with local partners to identify adaptation options

Enshrined within the co-production process to carry out all our activities in Malawi and Tanzania, UMFULA has been committed to ensuring that our research process and findings have impact in our case study countries. Close collaboration with partners in the Rufiji Basin and the Lake Malawi Shire River Basin enabled us to jointly explore adaptation options for robust decision-making in a context of climate and other socio-economic and environmental changes.

Workshop with Rufiji Basin Water Board, Tanzania, 2016

Workshop with energy, agriculture and water stakeholders, Malawi, 2018

Contributing to national policy processes in Tanzania and Malawi

We had several opportunities to provide inputs into national policies and strategies in Malawi. For example, we regularly engaged with the National Technical and Steering Committees on Climate Change in Malawi.

We provided comments on the draft National Resilience Strategy and its Implementation Plan. Among our recommendations was the need to consider longer-term climate change and variability, and to strengthen the details of tangible interventions under the four pillars (agriculture, risk reduction and early warning, livelihoods and social protection, and catchment management), with an emphasis on greater integration.

Key findings are also being provided to members of the National Planning Commission tasked with developing the new long-term development vision for Malawi.

UMFULA Tanzania and Malawi Climate Briefs published in 2017

At the invitation of our partner, the Department of Climate Change and Meteorological Services, we also provided inputs to Malawi's Third National Communication to the United Nations Framework Convention on Climate Change (UNFCCC) (Chapter 4 on climate projections). As well as making structural recommendations relating to the presentation and explanation of projections, we provided a set of future projections based on country climate briefs we produced in 2017 (Mittal et al., 2017).

Sharing UMFULA research through public engagement activities

Highlights of our public engagement activities in Malawi include presentation of a range of UMFULA findings at Malawi's first National Adaptation Symposium in 2018 and co-hosting a panel discussion in November 2017, together with the Civil Society Network on Climate Change (CISONECC), on 'How climate information can build a resilient Malawi', with speakers from the Environmental Affairs Department, Department of Climate Change and Meteorological Services and the United Nations Development Programme, as well as UMFULA and CISONECC.

Panel discussion: 'How climate information can build a resilient Malawi?', Malawi, 2017

Clinic session with students at the University of Dar es Salaam, Tanzania, 2018

UMFULA side event at Africa Water Week, 2016

In Tanzania, we engaged in universities, through regular lectures and clinic sessions with students, at Sokoine University of Agriculture and the University of Dar es Salaam. We were also one of the facilitators of the Africa Climate Leadership Programme (AfriCLP) held in Dar es Salaam in 2018, addressing challenges in delivering climate services on the continent.

Africa-wide, we participated in Africa Water Week in 2016 and 2018 with, for example, a side event in 2016 on the theme of climate resilience and the connections between the water, energy and food sectors in east and southern Africa, with speakers from the Government of Kenya and the UK's Department for International Development.

We led and participated in several open webinars to present emerging and key findings to a diverse and international audience (for the video recordings, see www.futureclimateafrica.org/videos):

- What you've always wanted to know about central and southern Africa's climate by Neil Hart
- How can climate models be improved over Africa? by Rachel James
- Policy coherence for sustainable development by Joanna Pardoe, Andrew Dougill, Katharine Vincent and guest Martin Sishekanu from Zambia
- Lessons in co-production of climate services from African case studies by Suzanne Carter, Anna Steynor, Katharine Vincent, Joseph Mutemi, Katinka Lund Waagsaether, Tufa Dinku and Emma Visman
- Ten principles for good co-production in African weather and climate services by Katharine Vincent, Emma Visman, Anna Steynor, Katinka Lund Waagsaether and Suzanne Carter

Partnership with National Meteorological and Hydrological Services

Engaging the national meteorological and hydrological services in Malawi and Tanzania was an essential component of UMFULA's knowledge-sharing and mutual capacity-building efforts.

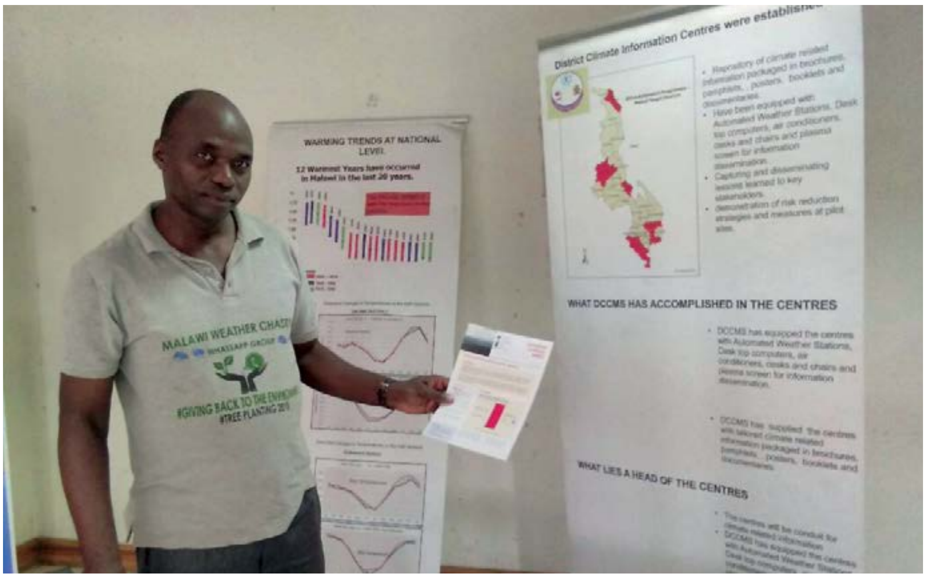
The UMFULA team partnered with Malawi's Department of Climate Change and Meteorological Services (DCCMS) throughout the project, which included inclusion in project planning processes, a series of visits and information-sharing.

UMFULA briefs at DCCMS stand, World Meteorological Day, Malawi, 2018

Highlights of our collaboration include briefs that we co-produced to outline future climate in Malawi, based on results of the existing global climate models (Mittal et al., 2017). The content and presentation reflected demands of in-country stakeholders as expressed to DCCMS. These briefs were subsequently used by the Department to raise awareness about climate change and its impacts at the World Meteorological Day Celebrations of 2018.

We worked together with DCCMS and provided inputs to Malawi's Third National Communication to the UNFCCC (Chapter 4 on climate projections).

We were also in contact with the Tanzania Met Agency (TMA) and a small group of UMFULA early career researchers visited TMA in 2018 to share findings from our work on climate processes for the region and how they impact Tanzania.



UMFULA briefs at DCCMS stand, World Meteorological Day, Malawi, 2018

CONCLUSION: IMPROVING THE USE OF CLIMATE INFORMATION FOR ADAPTATION IN CENTRAL AND SOUTHERN AFRICA

Based on UMFULA's research, what combination of model outputs, impact scenarios and decision-support tools improves effective use of climate information for adaptation in an African context?

Understanding the likely future characteristics of climate risk is a key component of adaptation and climate-resilient planning. UMFULA has made major advances in understanding rainfall regimes in central and southern Africa, including the role of features such as cloud bands, the Angola Low and South Indian Ocean high pressure systems. These findings have allowed assessment of the ability of climate models to simulate these processes and their influence on current and future climate in the region. However, it remains the case that future climate projections and impacts are highly uncertain, particularly for rainfall conditions which are critical for social and economic activities.

Given future uncertainty it is important to design approaches that are strongly informed by local considerations and robust to uncertainty, i.e. options that work reasonably well across a range of uncertain future climate (and other) conditions. This approach exemplifies decision-making under uncertainty. It allows us to inform decisions being made now, without having to wait for possible reductions in uncertainty.

Choosing the right tools and approach for climate risk assessment and adaptation to suit the scale of the decision allows a suitable trade-off between robustness and resources required (time and expertise) for analysis. There is a continuum moving from a simple light touch approach suitable for many small and short-lived decisions (for example, small-scale water and sanitation technologies) through to an increasingly detailed approach for major long-lived decisions such as irrigation projects and dams.

In the medium term, policy decisions require careful cross-sectoral planning. This is particularly necessary in cases involving large investments, long life-times, critical trade-offs and irreversibility, where there is a strong argument for assessing resilience to future climate change. River basin infrastructure exemplifies this.

In both UMFULA's case studies in Malawi and Tanzania, decisions in the water–energy–food nexus are subject to both climate and other aspects of future uncertainty. Values and trade-offs are inherent to these decisions, and hence consultation with a wide range of stakeholders is important. Co-production provides opportunities to define problems, to communicate complex information about changing climate risks, to prioritise responses, given attitudes to risk and pressures from often critical non-climate factors, and to make and implement decisions.

Consultation with stakeholders highlights the importance of political influences, policy process and local perspectives, and the complex ways in which they affect decision-making processes at all levels.

The process of partnership embedded within co-production contributes to building societal and institutional capacity to factor climate risks into long-term planning in Malawi, Tanzania and more widely in southern Africa. It also builds the capacity of researchers to better understand real world decision contexts in which climate change is one of many important factors.

UMFULA OUTPUTS

For updates, see www.futureclimateafrica.org

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Degrees

Malawi

Emmanual Likoya, MSc Climate Change and Development, University of Cape Town (dissertation title: Attribution of the risk of extreme flood events to climate change in the context of changing land use and cover: Case study of the Shire River basin flood of 2015)

Diana Mataya, MSc Environment and Development, University of Leeds (dissertation title: Role of capacity building for development and implementation of climate change adaptation programmes and policies in Malawi)

Tanzania

Emanuel Lorivi Moirana, MSc Wildlife Management and Conservation, Sokoine University of Agriculture (dissertation title: Climate variability and climate information use for water resources conservation decisions in the Kilombero River Catchment, Tanzania)

Innocent Patrick Lyamuya, MSc Integrated Water Resources Management, University of Dar es Salaam (dissertation title: Impacts of climate change on irrigation water requirements for improved irrigation water management and planning in the Mbarali River catchment)

Magdalena Mkhandi, MSc Environmental Technology and Management, Ardhi University (dissertation title: Impacts of climate variability and change on hydrological extremes and urban infrastructures in the Ifakara Township)

Edmund Mutayoba, PhD Engineering Science and Technology, Sokoine University of Agriculture (dissertation title: Uncertainty Reductions in Model Predictions at the catchment scale in the Upper Great Ruaha River sub-basin)

Weruwetsa N. Ngowi, MSc Environmental Technology and Management, Ardhi University (dissertation title: Processes for climate change adaptation planning in the water sector, looking at the case of the Kilombero sub-catchment)

Ruth Pallangyo, MSc Natural Resource Assessment and Management, University of Dar es Salaam (dissertation title: Assessment of availability, access and use of climate information by small holder farmers in Kilombero Valley)

South Africa

Balungile Gumbi, BSc Honours Hydrology, University of KwaZulu Natal (dissertation title: Using water disaster related data for preventive planning and management in Malawi)

Shenge Mthokozisi Buthelezi, BSc Honours Hydrology, University of KwaZulu Natal (dissertation title: Ground-truthing civil society's weather observations in Malawi)

UK

Amy Creese, DPhil Geography, University of Oxford (dissertation title: Climate change in the Congo basin: evaluating coupled models)

Robel Geressu, DPhil Civil, Environmental and Geomatic Engineering, University College London (dissertation title: Many-objective design of reservoir systems – Applications to the Blue Nile)

Callum Munday, DPhil Geography, University of Oxford (dissertation title: Controls on present-day and future rainfall over southern Africa in coupled climate models)

Degrees underway

Emma Howard, DPhil Geography, University of Oxford (dissertation title: Synoptic time-scale rain-producing weather systems in tropical southern Africa)

Simphiwe Ngcobo, PhD Hydrology, University of KwaZulu Natal (dissertation title: Hydrological impacts of climate change: implications of water stress on sugarcane yields across southern Africa)

Lizeth Nompumelelo Nkambule, MSc Hydrology, University of KwaZulu Natal (dissertation title: Modelling the impact of climate change on smallholder sugarcane and tea crop yields in the Shire River basin, Malawi)

Xolisile Yende, MSc Hydrology, University of KwaZulu Natal (dissertation title: Investigating the effects of climate change on the productivity in commercial sugar cane farming and milling and effectiveness of response management strategies in in Malawi and South Africa)

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Shire Valley, Malawi, 2016

Rufiji river, Tanzania, 2017

FUTURE CLIMATE FOR AFRICA

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