Save the Children

Policy Paper
Integrated Watershed Approaches to Mitigate Slow Onset of Droughts

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Final Report (1 of 2)[†]

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Contents

Executive Summary

This paper is part of study commissioned by Save the Children Somalia/Somaliland to explore watershed restoration as a means of disaster mitigation and disaster proofing. The document reviews publications and studies in the Horn of Africa and adjacent regions to cover work on watershed development as a strategy for disaster proofing and risk reduction. The overall purpose of this exercise is to provide a scientific context and justification for a watershed restoration approach for disaster proofing and vulnerability reduction. This exercise is an important pre-requisite to designing strategies and proposals for field level interventions. The document also tries to identify gaps between the scientific research community and practitioners as in it attempts to tie local, community based action with global and regional research on climate change and hydrological modelling which can inform regional policy decision making and local level actions.

Climate predictions and implications

There is increasing scientific evidence that climate change is going to trigger various local changes which will adversely affect natural resources in the coming decades. There is evidence that these changes have already taken place and that communities highly dependent on these resources, such as pastoralists, will have to build coping strategies to adapt appropriately. Expected changes include an overall increase in temperatures across Africa and a decrease in precipitation in most part of the Continent. Most models estimate an increase in precipitation in Eastern Africa. There is also broad agreement that the frequency and intensity of droughts in the region will remain similar or increase. The frequency of extreme weather events is likely to increase. Thus there is increased likelihood of very high temperatures, high intensity of rain followed by prolonged dry periods.

Africa has amongst the largest number of people living in marginal agricultural areas. Climate change is likely to make upto 50% of agriculture in these areas unviable. Pastoralism is the mainstay of the economy in the Horn of Africa. Increased dry periods, high temperatures and shortening in the number of rainy days is likely to reduce productivities of pasturelands significantly and alter the availability of water in natural and man made water harvesting structures. Coping strategies that have been observed with the marginal agricultural and pastoral communities in the region largely attempt to diversity resource use, particularly in the absence of formal systems to cope and provide social security. The implications are dire.

How can watershed restoration help?

One way of mitigating these impacts is to improve the capacity of communities to manage their resources so that available resources are used optimally and conserved for emergencies. Watershed restoration and management has been demonstrated as a successful strategy across the world. The knowledge of resource management allows protection of resources from climatic variability, increased incomes and wider livelihood options. Experiences from the Niger show that communities can “buck the trend” in terms of increasing the resource base when most predictions were that the region was heading to desertification. Better managed watersheds will allow communities to build various disaster mitigation strategies into their use of resources. Many of these activities can be initiated at low costs through building capacities and small budgetary investments. To list a few:

- Soil and moisture conservation will result in improved biomass production.
- Water harvesting structures will increase the duration of water availability as surface storage and substantially improve ground water recharge.
- Introducing and supplementing existing forestry and agro-forestry efforts will improve availability of energy and forage in lean periods as demonstrated successfully in Niger.
- Pastureland management strategies can be developed to improve quality and quantity of forage and set aside grazing areas for periods of drought and emergency.

There are, however, a number of operational issues which need to be addressed. The management structures, ownership and control over resources is perhaps the most important. Capacities, in term of human and financial resources, of communities to take up these tasks in addition to their existing work is another major issue.

Gaps and opportunities

Bridging the community scale planning for natural resource management to the climate change models is a crucial step that is missing in most developing regions of the world, Africa in particular. There are many positive spin-offs from linking local level resource mapping with hydrological modelling. For one, local communities are in the best position to monitor field conditions - this opens up huge potential for collaboration, or action research. For instance, collection of training sites, collection of ground control points, managing data loggers for meteorological and hydraulic stations. In turn the local communities can be better informed by the models and helped to design appropriate restoration strategies.

At the local level, communities need to take up restoration activities and manage their resources, ideally, in an equitable and sustainable fashion. This requires drawing up of local plans, implementing the activities and their monitoring and evaluation against expected outputs and outcomes. At the watershed level, research agencies need to downscale and link global climate models so they can feed into hydraulic models which in turn inform local decisions. For instance, the likely flow rates in different streams, the likely sediment transport and points of erosion and accretion. At the regional level, much work is required to downscale global climate models so they are calibrated to finer scale climatic variables and drivers. The scale at which most models are operating are insufficient for regional and even less local level planning.

There are a number of gaps which need to be addressed. These need to be filled at various scales and through various mechanisms operating at these scales. At the policy level, governments and large non-government actors need to formulate and agree on a framework that ensures communities are assisted in managing their resources. While some work has taken place in Ethiopia and to a lesser extent, Kenya, many issues remain. These include ownership jurisdictional claims over natural resources and migratory rights of pastoralists. The absence of such as system greatly limits the scope of physical interventions for improving and managing the resource base. At the level of international and national research institutes, resources need to be set aside for downscaling climate models and linking them to hydrological, land use and ecosystem services models and tools. Without this, scientists will continue to (largely) speak in a different language and to a different audience with little and no contribution of information which could help local level policies and planning. Governments and non-government agencies also need to establish better links with academic agencies so there is better flow of information in both direction.

Closer to the ground, there are large gaps in the capacities of both development agencies and the communities to undertake resource management and restoration. Universities providing technical training need to fill in part of the gap in human resources for livestock management, veterinary care, pastureland management, appropriate agro-forestry and reforestation techniques. Basic engineering and construction skills are required at the implementing agency level and with the community. Finally, capacities in undertaking field surveys and intervening for restoration activities need to be built. These require documentation and training on tools and techniques for soil and water conservation and nursery raising and planting, among others. The gaps in availability of meteorological and hydrological data need to be addressed before either regional climate modellers or hydrology and land use modellers can provide meaningful results.

Overview of this document

The document has four sections each (except the introduction) has a non-technical introduction and a summary at its end. The body of most of the chapters is fairly technical as it tries to draw lessons from scientific literature on the subject of climate change and hydraulic modelling.

The introductory chapter provides a brief background to the study and its scope in a non-technical language. It also provides necessary information about the study site and of Save the Children, who supported this work. Chapter two covers literature on climate change and summarises predictions pertaining to Africa and the study site. Work done by the International Panel on Climate Change as well as significant independent studies are summarised. The third chapter scales down to regional levels and examines how climate models have been used to make regional predictions and to link to hydraulic and land use/land cover models. A separate review of hydraulic models is also provided. The chapter tries to highlight gaps in linking climate and local regional models and problems faced by researchers in setting up local models for scenario building so they can be used to support ground level planning.

The concluding chapter (chapter 4) deals with studies and field experiences in implementing watershed and natural resources restoration and climate adaptation projects. It covers a number of case studies and experiences from research, largely in Africa and seeks to draw out the major lessons in terms of what the crucial ingredients for successful community response to natural disasters is.

The appendix provides a summary of the climate scenarios and briefly lists some publications on methods that can be used for participatory natural resource management.

1 Introduction

Scope of the study

This desktop research attempts to build an argument that relief agencies operating in Africa need to consider expanding their portfolios from emergency response to more long term disaster resilience and mitigation. The paper builds its argument by using published articles both in peer reviewed journals and reports, such as this one, commissioned by agencies in the region.

The argument is as follows:

There is a growing body of literature and evidence (summarised in chapter 2) that climate change will result in fundamental and long term changes in the way natural systems work in Africa. Some of these changes are likely to "push" ecosystems out of their range of resilience. In other words, systems such as pastoralism and rain-fed agriculture, are likely to face prolonged stress. Some of these systems will degrade as a result of these changes as their functional components break down. Communities dependent on these systems will therefore face an acute shortage of ecosystem goods such as fodder, forage, fuel and water. Furthermore, these effects will be long term and in may cases, will not be reversible and ecosystems will degrade. Pastures will tend towards desertification and agricultural areas will tend toward grasslands.

One crucial objective of climate models is that they link up with more regional and local scale modelling systems. Once this is done, predictions can be used to inform local decision making and answering questions such as - how much rain is likely to reach the Sanaag region next month and what will be the expected temperatures. Some of this information is already being provided by agencies such as the FEWSNET. Chapter 3 summarises the kind of work hydraulic models have been put to around the world. Much of this work is to inform local decision makers on decisions such as when and where to plant, which area is likely to erode and where the water and mud will go, how much water will be stored and for how long, if a check dam were put across a particular stream. There is however, a serous gap. Climate models don't (yet) talk to the local and regional hydrological models. Or, hydraulic models are still largely disconnected from the likely scenarios of climate change. Therefore, these models can't yet be used to generate likely local scenarios for the future.

While natural resources management would be better informed by these models and scenarios, there is already enough experience (chapter 4) to know that it is among the only strategies which can allow communities to adapt to climate change. Most NRM strategies are build on a system of adaptive management. In other words, learnings from field experience inform subsequent strategies. Such management systems are highly robust as they are flexible and responsive to environmental changes. Virtually all major agencies involved in disaster relief, climate research and livelihoods development have NRM as a core component of their strategy. Large sums of money are pledged to projects to strengthen the natural resource base of communities. Most of these deal with water and land management.

Given the above, there is a strong case for Save the Children to extend its activities to natural resource management with communities. This would enable the organisation to not just "respond" to emergencies, but to facilitate communities to confront these emergencies. A well managed watershed will provide more fodder for longer and more water for longer than one that isn't. Agro-forestry and afforestation can improve availability of fuel and forage round the year. The case studies in chapter 4 provide valuable insights into how communities have moved from being highly dependent on external aid to a more selfreliant status with wider set of livelihood options.

Watershed approaches are among the best strategies to approach natural resources management because they deal with the issues in an integrated fashion. Using watersheds as units of management ensures that natural boundaries and processes are built into the planning stage. Furthermore, they can be informed by hydraulic and climatic research, if and when the scientists and research institutes get their acts together.

Study site

This review of literature is largely, based on work done in the Horn of Africa (Eritrea, Djibouti, Ethiopia and Somalia) and Kenya. Specific attention has been paid to literature concerning Somalia and Somaliland region and North Eastern Kenya (Wajir province), the bulk of the grey literature reviewed pertains to this region.

A description of the Sanaag region follows[1]:

"Sanaag region is the largest region in Somaliland occupying about 37.5% of Somaliland. It is located on the eastern side of the country bordering Sool region to the south, Galbeed region to the west and approximately 380 kilometers of the Red Sea coastline to the north and has numerous natural resources and beautiful diverse landscape. Sanaag region has a population of between 180,000 and 200,000 people. The capital of Sanaag region is in Ceerigavo.

The region is divided into six main districts namely, Ceerigavo, Gar'adag, Badhan, Lasqouraay, Dahar and El Afweyne, with Ceerigavo Town as the regional capital and the latter as district capitals. The livelihood system in the rural area of the region is predominantly pastoral. The region is remote and mountainous by nature; this difficult physical terrain has resulted in poor infrastructure and limited development.

During the recent decades, the region became one of the most disaster prone areas in country due to climate change variability together with other factors, which in combination curtailing the local people abilities to cope with their most predominant risks – drought.

Regarding to the watershed health, though a quantitative data on the extent of changes/natural degradation is lacking and it is difficult to clearly pinpoint the exact causes and effects of change taking place, there is clear evidence indicating the continuous decline in the health of watershed and natural resources.

On the other hand, there has been increasing community concern about these negative changes and, therefore, they have been attempting to adapt but at the same time missing crucial external support to take them through these changes. The need to ensure that the people in these kind of ecosystem adapt and or are less exposed to the the vagaries of climatic patterns, there is a need to address the underlying causes that have been led to an erosion of rural people resource and asset bases."

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[1] From Save the Children background note on Somaliland.

About Save the Children

Save the Children Somalia / Somaliland is a non-governmental organization whose mission is to fight for children's rights and deliver immediate and lasting improvement to children's lives worldwide. SCISOM has been operational in the Greater Somalia for over 40 years. Currently Save the Children operates programmes that span relief to development with a wide range of programming in Health, Nutrition, Child Protection, Child Rights Governance, Vocational and Skills Training, Education and Food Security & Livelihoods working in Somaliland, Puntland and Central and South Somalia. Save the Children works to ensure quality programming on the ground which forms the basis to advocate for greater changes in policy and practice at regional, national and global levels.

2 Climate predictions for Africa - likely impacts on rainfall, temperature and land cover

Background

This section summarises the state of the science in climate change and hydrology applications that are extensively used by the scientific community to predict likely changes in rainfall, temperatures and consequently land cover and productivities of regions. The purpose of this technical review is to demonstrate that while great strides have been made in the ability to predict events, there remain large gaps, particularly at the reginal level, where these tools are insufficiently developed to provide decision support. This is not to suggest that the tools briefly reviewed are not useful. On the contrary, additional work is required so these tools are able to inform local communities so they may take reasonable steps to mitigate disasters and extremes in precipitation and temperatures.

IPCC and related publications

Africa has received insufficient attention in climate research[1] and thereby has few regional or sub-regional climate change scenarios[2]. The IPCC report on Africa attributes this to lack of human and computation resources[2]. The report adds "Africa is one of the most vulnerable continents to climate change and climate variability, a situation aggravated by the interaction of 'multiple stresses', occurring at various levels, and low adaptive capacity". Regardless, the findings of the IPCC remain limited to the regions described in figure 1, in which the project site falls under the EAF grids. As has been noted in the IPCC report itself, the multi model dataset tries to put together a wide range of predictions, a consensus on climate change in Africa, particularly at the regional level remains elusive[3]. The various country profiles themselves can be accessed from on-line web sites[3].

The basic findings of the IPCC reports are[4]:

Temperature An increase in annual mean temperatures from 3 to 4°C are expected compared to the period of 1980–1999, with less warming in coastal areas. Longer term predictions are from 3.7 to upwards of 9°C for the period of 2070–2099.

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[2] This is evidently being addressed: http://www.aiaccproject.org/aiacc_studies/AF07.html,

[3] http://country-profiles.geog.ox.ac.uk/

[4] A number of limitations in the models have been stated by the IPCC which make the predictions on precipitation inconsistent and unreliable.

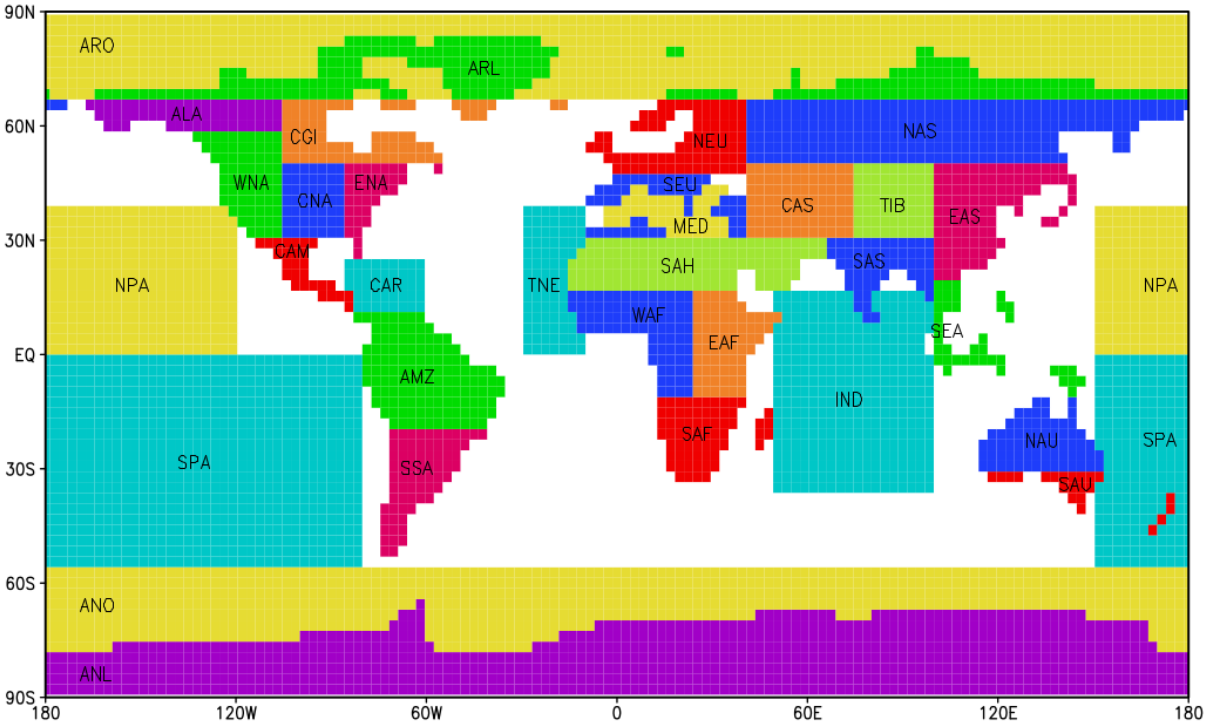

Figure 1: **32 world regions employed in reporting sub-continental climate change. From Ruosteenoja, K., T. R. Carter, K. Jylhä, and H. Tuomenvirta. Future Climate in World Regions: An Intercomparison of Model-based Projections for the New IPCC Emissions Scenarios. Vol. 644. Finnish Environment Institute Helsinki, 2003.**

Precipitation A decrease of 20% along the Mediterranean coast extending into northern Sahara while an increase of 7% in tropical and eastern Africa. The winter rainfall for southern Africa is expected to decrease by 40%. An increase in rainfall is also predicted for equatorial regions falling between north of 10°S and east of 20°E.

Water Increased stress in northern and southern but decreased stress in western and eastern Africa.

Stream flow The range of climate induced changes for 2050 are a pan Africa decrease of 15% in streamflow to an increase of 5% above the 1961-1990 baseline. All countries in souther Africa, except for South Africa itself will face a significant reduction in stream flow.

Malaria Other than Sahel and southern central Africa, there is likely to be a spread of malaria, including incursions of malaria into malaria free highlands of Ethiopia, Kenya, Rwanda and Burundi as well a spread into southern Africa.

Agriculture & pastoral Other than parts of Ethiopian highlands and parts of southern Africa such as Mozambique and irrigated lands, there is likely to be a very significant drop in productivity of agricultural and pastoralist production systems as shown in figure 2.

Livestock The report limits its observations to livestock farms and not migratory pastoralists but clearly indicates that increases in temperature will relatively favour small and adapted livestock (sheep, goats and camels) but be detrimental to large livestock (cattle).

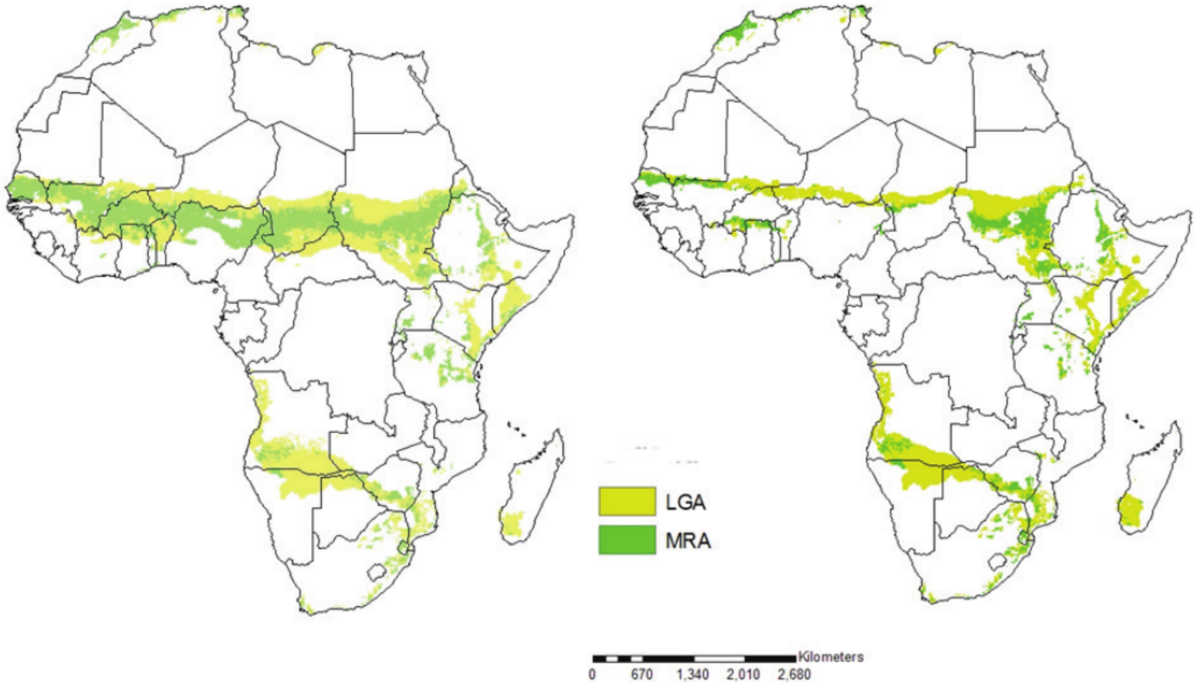

Figure 2: **Agricultural areas within the livestock-only systems (LGA) in arid and semi-arid areas, and rain-fed mixed crop/livestock systems (MRA) in semi-arid areas, are projected by the HadCM3 GCM to undergo >20% reduction in length of growing period to 2050, SRES A1 (left) and B1 (right) emissions scenarios. From Thornton, P. K., P. G. Jones, T. Owiyo, R. L. Kruska, M. Herrero, V. Orindi, S. Bhadwal, P. Kristjanson, A. Notenbaert, and N. Bekele. "Climate Change and Poverty in Africa: Mapping Hotspots of Vulnerability." African Journal of Agricultural and Resource Economics 2, no. 1 (2008): 24–44[4].**

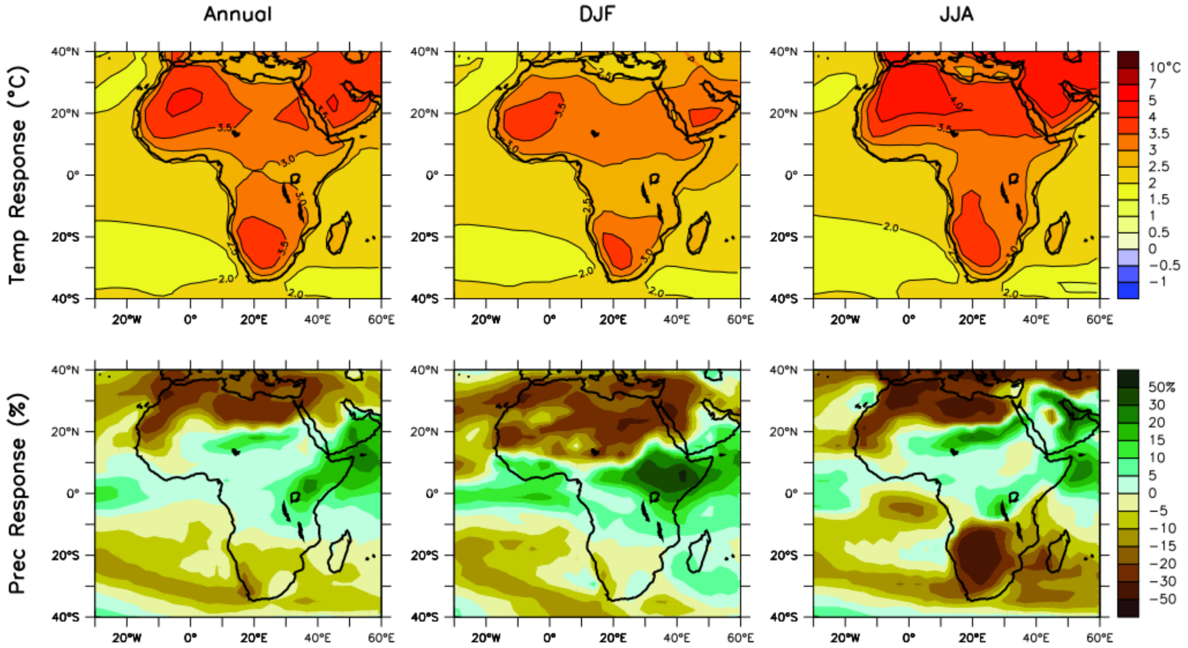

Figure 3: **The IPCC *MMD-A1B* predictions. DJF=>December, January, February; JJA=>June, July, August. MMD=>Multi model dataset, A1B=>Conservative scenario of low populations, high technology, clean and multiple souces of energy.**

Other publications

A review of the past decade and future content wide changes[1] pointed out a major gap in climate models was the poor incorporation of El Niño/Southern Oscillation (ENSO) which drives seasonal rainfall patterns, particularly during the short rains (Oct-Nov) in E equatorial Africa and long rains (Nov-Feb) in SE Africa, and complete disregard for land cover induced climate change and impact of aerosols in the models of the time[5]. Thus limiting itself to greenhouse gas driven changes. Hulme et.al., referred to lack of human and institutional investments in African climate research as one of the reasons for these gaps in information. It is precisely this gap that the Assessments of Impacts and Adaptations to Climate Change (AIACC) project[6] tries to address in part.

This phenomenon was however explained in greater detail in subsequent work, partly covered by the IPCC itself[5], which described how changes in the Indian Ocean sea-surface temperature (SST) affected rainfall patterns in the Sahel region of western and north-central Africa, together with likely feedbacks of land-cover on temperatures. The latter however was seen to be secondary to other drivers such as sea surface temperatures, models of which “reproduced the historical record of Sahel rainfall”[6].

A subsequent paper by Giannani et.al., 2008[6][7], advances made in understanding environmental changes possibly triggered by climate change were revised and included the integration of remotely sensed vegetation cover data, land cover–precipitation models and effect of sea surface temperature (SST) on precipitation. Regardless, their position on the ability of models to predict future change at the regional level remained sceptical.

Giannini et.al., summarise the two dominant continental scale patterns related to variability of surface temperatures of the ocean: “(1) a continental-scale drying pattern related to enhanced warming of the southern compared to the northern tropics and to a warming of the tropical oceans, (2) the impact of ENSO on the tropical atmosphere and oceans around Africa.”[6] They further state that seasonal patterns of rainfall in Africa can be explained based on the “slow evolution of SST anomalies”. In a latter summation of literature Paeth et.al., 2009[3] re-affirm the primary role of oceanic temperatures and the secondary effect of “land surface conditions, that is, vegetation cover, albedo, and soil moisture”.

The Horn of Africa has been shown to exhibit a “dipole” pattern where precipitation was shown to increase in the northern but decrease in southern areas. This phenomenon has been observed by various authors [7], and tries to explain yet another of the complexities operating at the regional level.

Among the more regional climate predictions include the work by Paeth et.al., 2009[3] and unpublished results of a downscaled GCM for Somalia based on a disaggregation method using the conservative SRES-A1B scenario[8].

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[5] This paper is a decade old and used the IPCC-III models.

[6] http://www.aiaccproject.org/aiacc_studies/AF07.html, http://www.aiaccproject.org/aiacc_studies/AF20.html

[7] Simple and non-technical explanation about climatic drivers in Africa.

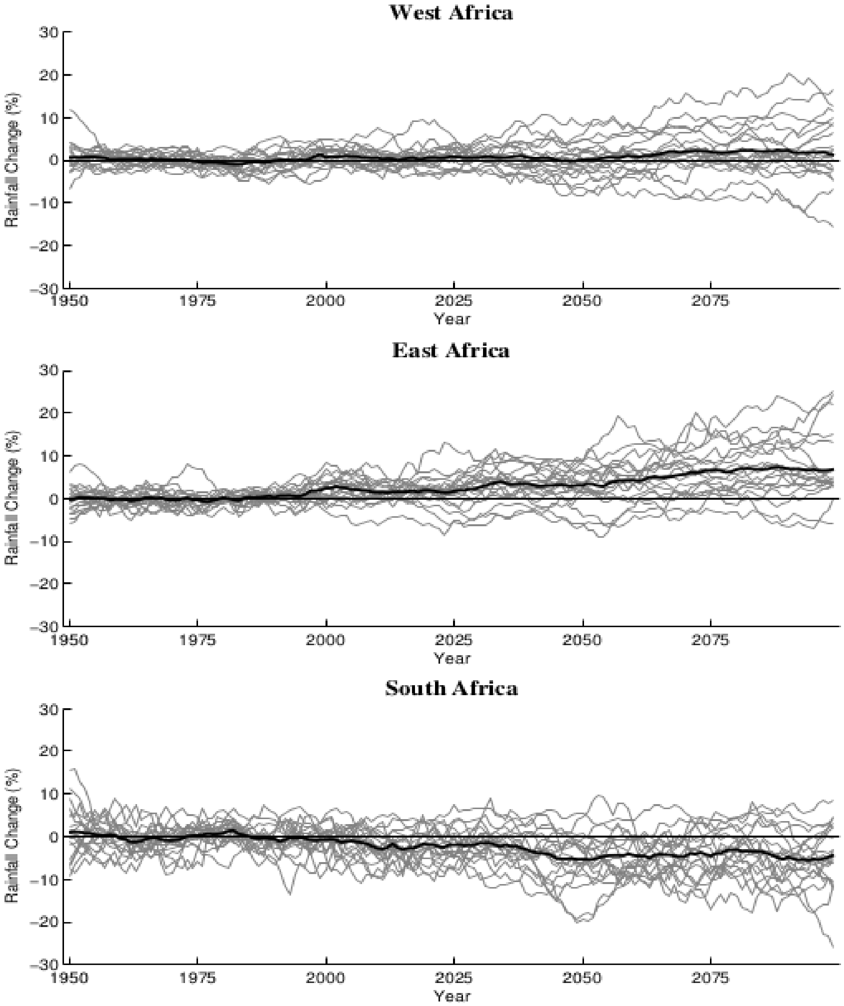

Figure 4: **Regional averages of precipitation in the IPCC 4AR model simulations; 20th century simulations from 1950 to 2000, and A1B scenario simulations from 2000 to 2100. Each grey line represents one model, and the thicker black line is the multi-model mean. From Giannini et.al., 2008[6].**

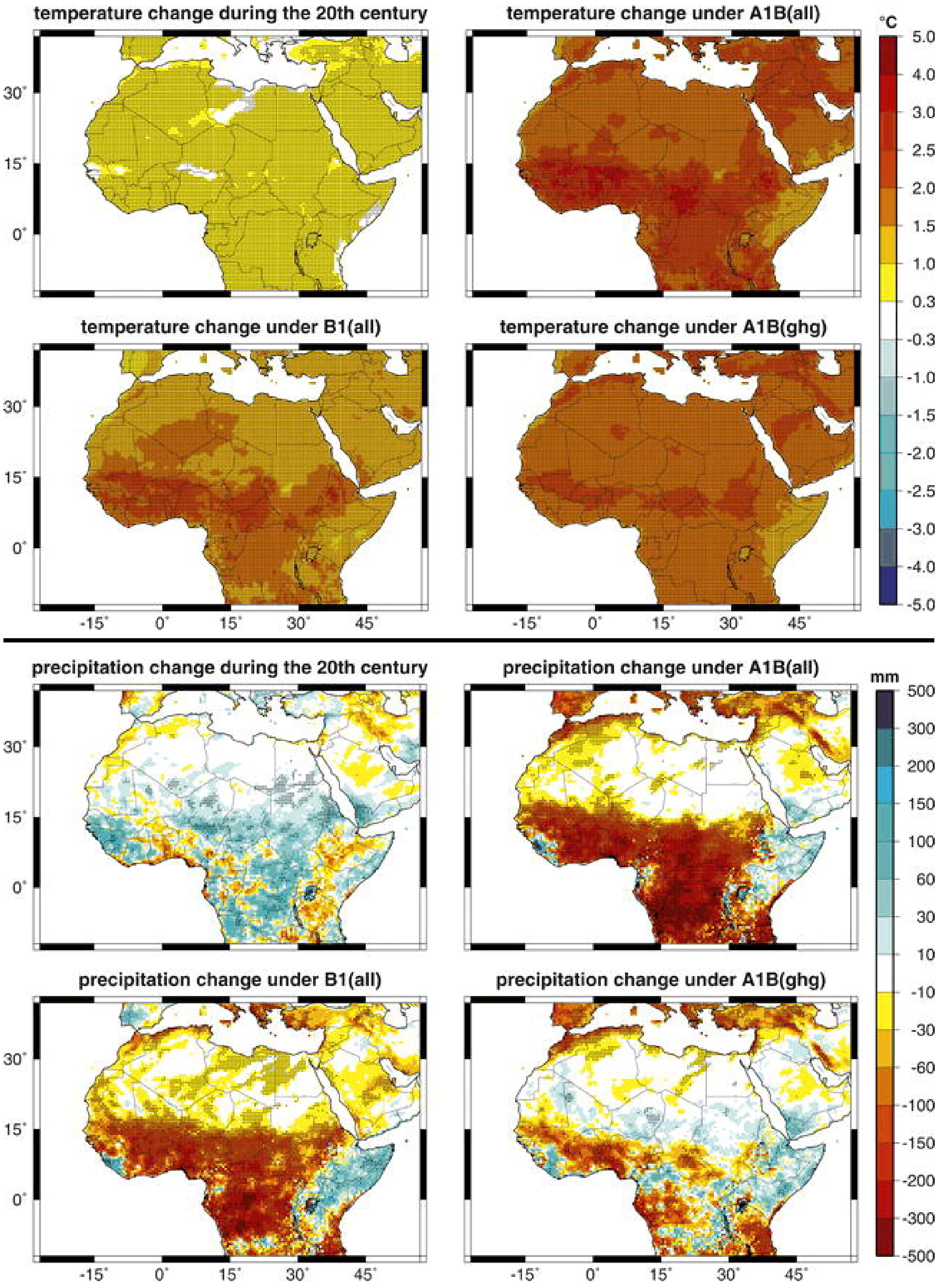

Figure 5: **Simulated ensemble-mean changes in annual near-surface temperature (top) and precipitation (bottom) expressed as linear trends (multiplied by number of years) during the (top left) twentieth century (1960–2000) and the projection period (2001–50) under the three different scenarios: A1B(all) = strong greenhouse gas emissions and land cover changes; B1(all) = weaker greenhouse gas emissions and land cover changes; and A1B(ghg) = strong greenhouse gas emissions and no land cover changes. Values statistically significant at the 5% level are marked by dots. From Peath et.al.,[3].**

Parameter	Author	Scenarios/climate sensitivity	Response
Annual warming across Africa	Hulme et.al., 2001[1] CCM	B1-low / 1.5°C & A2-high / 4.5°C	<0.2°C to >0.5°C leading to 2 to 6°C increased temperatures in 100 years.
Precipitatiin Sahel and S Africa		Median response	annual drying
Precipitatiin E Africa		Median response	annual wetting
Precipitation in E equatorial Africa	Giannini et.al., 2008[6] CCM	Median response	Increase
Precipitation in S Africa		Median response	Decrease
Temperature	Paeth et.al., 2009[3] RCM	Extreme events	increase by up to 6°C
Dry spells over West Africa		Extreme events	Increase
Precipiataion in Sub-Saharan Africa		Median response	20–25% decrease
Precipiataion in Horn of Africa		Median response	Increase
Temperatures across Sub-Saran and Horn of Africa		Median response	Increase 0.5 to 2.5°C depending on scenario.
South Somalia especially south east and north of Baidoa and Mandera	Mahmoud et.al., 2012[8], Downscaled GCM.	Median response	Increased rainfall
Sool and Sanaag		Median response	Reduced rainfall
Sool and Sanaag		Maximum and minimum	Increase in temperature

Table 1: **Climate predictions for Africa. Review papers spanning a decade. Preditions for 2050. Note Mahmoud et.al., 2012 is unpublished.**

Summary

Ocean Atmosphere General Circulation Models are based on a set of socio-economic scenarios which provide a starting point for simulations. These scenarios range from utopian and conservative to pessimistic but realistic. Each scenario provides different results for the same GCM as triggers such as carbon emissions vary considerably between these scenarios. Furthermore, there are over 20 major climate models that are considered in the IPCC. Few of these models agree with each other for the same input scenario. Thus the IPCC opted to pick median predictions for its report. It is worth noting that the bulk of the model predictions are based on conservative scenarios.

In spite being weighed towards favourable scenarios, the bulk of the predictions paint a gloomy picture for Africa as a whole an the Sahel region and Southern Africa in particular. All models for all scenarios point to an increase in temperatures across the continent. Predictions for precipitation indicate that it will decrease in most areas except parts of Eastern Africa. However the uncertainties in rainfall are also expected to increase in response to changes in land cover and consequent soil moisture and temperatures for the tropical and northern African region. Consequently droughts are likely to remain as present or even increase in intensity. Extreme weather events are also likely to become more common straining the resilience of natural systems even further.

3 Review of models used for scenario building at a local and regional scale with a focus on data requirements for setting up these models

Background

The eleventh Conference of the Parties to the Convention on Biological Diversity (CBD COP 11) concluded in Hyderabad India in October 2012 made a number of important commitments for conservation and restoration of ecosystem services. Among these were the targets 14 and 15 of the Aichi Biodiversity Targets Strategic Goal D, which is to “enhance the benefits to all from biodiversity and ecosystem services”. These goals speak of conserving and restoring ecosystem services, particularly those pertaining to water with a specific emphasis on needs of vulnerable communities. By doing so, it is believed, they will contribute towards “climate change mitigation and adaptation and to combating desertification” [9].

There is global recognition that functioning ecosystems are integral to livelihood security [10,11]. This is one of the basis of the millennium ecosystem services framework (MA)[12,13] which has allowed the integration of policy and conservation[14–17], at least in the theoretical realm[18–20]. The MA framework essentially replaces the concept of carrying capacity with a broader and more comprehensive understanding of how ecosystems work. It ties policy actions to trade-offs in ecosystem services by helping policy makers monetise what was earlier outside conventional economic thinking[21]. For example, the loss of water quality that would occur if a catchment were deforested[22]. By doing so, it provides policy makers a range of options in decisions and likely consequences. Furthermore, it allows predictive models to help inform such decision making. This has resulted in the growth of a new family of computer based decision support tools, some of which have been summarised by Waage et.al., 2011[23].

Watershed services, or more precisely hydraulic services, are perhaps the most easily identified and valued services from ecosystems[15]. A host of tools are available to quantify both surface and subsurface flows. A lot of attention is also presently being given to impacts on climate change on hydraulic services[24–26] and modelling extreme precipitation events[27,28]. Coupling hydrological models to climate models is increasingly common as it provides insights that policy makers might use for disaster mitigation planning. The need for building such scenarios or “stories” cannot be overemphasised, particularly for complex systems[29].

Downscaling global climate models

There are various assumptions that are made which influence the results of the simulations. First, the global models themselves assume various emission and socio-economic scenarios[30]. Second, there are various types of global models, each with their set of assumptions and modelling frameworks. The Intergovernmental Panel on Climate Change (IPCC) for instance used 22 models in its Fourth Assessment Report[31]. These models predict climatic variables with varying degrees of confidence, precipitation being at the lower end of the scale[32]. Third, to use predictions of GCM as inputs into hydrological models, the results need to be downscaled as hydrological models operate at scales which are finer by orders of magnitude. Two basic kinds of downscaling approaches are used - by using a finer (regional level) climate model within the GCM. These are referred to as regional climate models (RCM) or limated-area models. The second technique is to use statistical methods to establish relationships between climate model predictions and local climatic variables. A review of different downscaling techniques is provided by Xu, 1999[26] and in more detail by Maraun et.al., 2010[33].

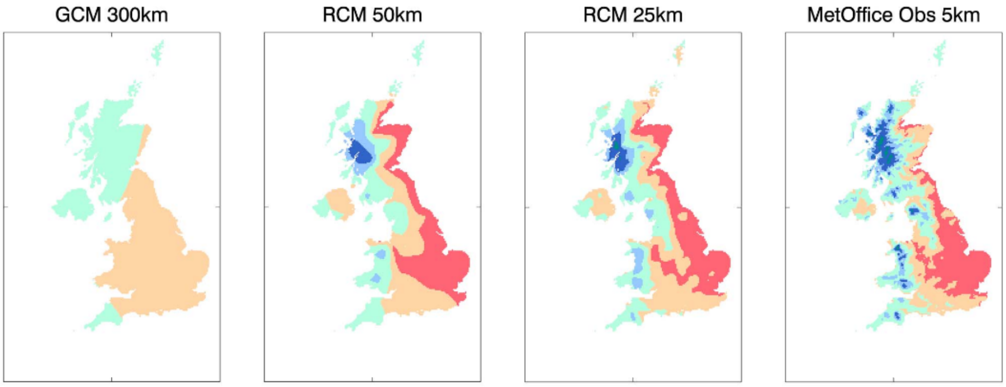

Figure 6: **Effects of downscaling as opposed to meterological observations. From Maraun et.al., 2010[33].**

Evidently this is not without consequence as downscaling techniques can greatly affect the results of subsequent modelling[34]. The outputs of the RCMs again vary based on the scenarios. However, the results appear to be more affected by the choice of CGM than either the type of RCM or scenario used for it[35, 36]. In another review of literature on downscaling climatic variables specifically for hydrological applications[34] it was found that most literature did not address the issue of how these models could be used for decision making for climate change adaptation and mitigation. A latter study by Chen et.al., 2012[24] showed that for a given GCM, the downscaling technique altered the run off predictions of the hydrological models substantially. They provide insights into statistical downscaling techniques in stead of RCMs for coupling GCMs with hydrological models. Statistical techniques have the advantage of being less computationally expensive, even though they are not physically based. To confound the picture further, African rainfall, the Sahel region in particular, has been shown to be affected by near surface temperatures which are related to vegetation cover[3].

Hydrological models have a number of features which make them attractive for regional predictions and coupling with climate models however there are also a number of inconsistencies in between the two[26] and a wide range of models and modelling approaches which makes the choice of model difficult[25]. The choice of hydrological model needs to be principally guided by the application and scale in question, available data for parametrising the model and the calibration and validation of its outputs.

Surfleet et.al., 2012[25] used three hydrological models operating at different scales, from multi basin to basin to site specific, and covering different processes - from soil infiltration (multi basin) to surface runoff modelling and surface-ground water coupling at the site scale. They compared the fit of the models to historical hydrological data and found that the finest scale, site specific models performed well in heterogeneous basins while the large scaled models provided a more cost effective solution and worked better in regulated areas, such as those below dams. They further suggest that model choices need to be informed by measuring uncertainty and natural variability in input parameters and errors introduced from processes such as groundwater interactions in low flow scenarios.

Literature on watershed modelling

Most literature on watershed restoration is closely linked to hydrology and covers transport of sediments, nutrients and pollutants and impacts of land use changes on stream flow and ground water recharge.

Sediment transport [37] and transport of nutrients and pollutants [38] are important criteria for measuring effectiveness of watershed restoration. Changes or reduction of stream discharge, increased variability of stream flow and ground water recharge have also received some attention [39,40]. This is often associated with disruption of stream flow or upstream land use/land cover changes and deforestation [41,42] (for a review see Agarwal et.al., 2001[43] and Bruijnzeel, 2004[44]). Impacts of global climate change on stream flow and riparian habitats and wetlands is another area of growing concern as it often results in disruption of associated watershed services [45].

Monitoring environmental and hydraulic variables on field can be both expensive and time consuming. Physical models such as the Soil and Water analysis Tool (SWAT), however, derive “reasonable” values for a great number of these parameters [46], making it possible (but not ideal) to set them up for un-gauged catchments and data deficient areas. This makes SWAT a popular tool to for monitoring [47–49] and as a decision support tool [50,51,37]. Methods for decision making on the basis of multiple criteria are currently gaining prominence. The advantage of these tools is that they “assist policy makers in evaluating and selecting a suitable strategy from among some feasible plans”[52]. Studies where comprehensive analysis has been undertaken with the broad objective of “preserving ecosystem integrity while maintaining sustainable benefits for human populations” [53] are also gaining prominence. This approach to WSD moves from treating symptoms to treating causal processes which operate at landscape scales.

Field level data requirements

Precipitation and to a lesser degree, temperature are two of the important drivers of hydrological models which have direct relevance to the output of global or regional climate models. They are also drivers for a range of other parameters such as vegetation cover, and over longer periods, soils and topography. There are a range of other important parameters that are needed by most models. The spatial and temporal scale of some of the parameters is another important variable that determines the accuracy of the models. The table below tries to summarise the major parameters and derived layers required to operate the bulk of hydrological and surface transport models used today[8].

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[8] Note that these change based on the model in question

Parameter	Layers	Derived layers	Temporal resolution	Spatial resolution
Soil	Texture, erosivity, permiability, capacity	L factor, K factor, mannings roughness	Not important	Depending on variability
Temperature	Temperature (max/min), Relative humidity (max/min)		Important on a daily scale	Important based on land cover variation
Precipitation	Rainfall, snow		Important, especially for modelling extreme events	Important based on desired model scale
Land cover	Land use, ndvi	% cover	Seasonally important	Important based on model scale
Digital elevation model	Elevation	Slope, aspect, gradient	Not important	Important based on topography of site
Soil+Precipitation		Saturated flows, infiltration excess flows		
Temperature+RH+Vegetation		Potential evapotranspiration, ET		

Table 2: **Various parameters and variables that influence the accuracy of hydrological model predictions.**

Summary

There is a wide range of sophisticated models covering hydrology, land use-land cover and ecosystem tradeoffs, which are appropriate for regional and local level planning. However these tools are constrained at both ends of the scale for data. At the higher scale, there is not enough data from downscaled models for the region. Also, methods adopted for downscaling rely on statistical techniques rather than the more computer and data intensive regional climate models. This has been aptly summarised by Jones and Thorton, 2008[54] “There is currently a mismatch between the kind of localised climate change impact information that is urgently needed, and what can objectively be supplied”.

However there have been a number of attempts at linking downscaled models for hydrological and land use predictions or scenario building. These papers typically dedicate a large discussion on their limitations, but are able to provide various on-ground scenarios based on the special IPCC report on emission scenarios.

Setting up independent, non-climate linked, models for local level planning also has serious limitations. Data is unavailable or too sparse to set up or parametrise many of the available tools. As a result the majority of publications utilise tools which estimate reasonable values based on interpolations or known relationships between missing parameters and more easily available data. For instance, potential evapotranspiration values derived from available data on temperatures and relative humidity. Results from such studies, even though often indicative, are very informative. These tools have informed major decisions in resource management, such as the New York water supply system, as well as local actions on appropriately positioning checkdams or identifying areas of likely erosion and accretion in streams.

4 Case studies and experiences from watershed development projects in the region and global lessons

Background

There is overwhelming evidence for watershed restoration as a strategy for disaster risk reduction through building resilience of communities against climate change and eventualities such as the slow onset of droughts. This is a major theme of the Hyogo framework for action detailed during the World Conference on Disaster Reduction at Hyogo Japan in 2005[9]. The ongoing 18th Conference of the Parties (COP18) to the United Nations Framework Convention on Climate Change (UNFCCC) and the 8th Session of the Meeting of the Parties (CMP8) to the Kyoto Protocol[10] has identified sustainable land and water management as one of the major areas for investment. A number of agencies have pledged support to proactive initiatives in natural resources management and watershed restoration to this end. these include the World Bank-GEF[11], DFID[12], African Development Bank[13], USAID[14] and the European Commission[15] among others.

This section presents some of the lessons from studies on community based natural resources management, particularly from a climate related framework. There are a number of records both in formally published as well as grey literature on how local communities have taken up environmental management in order to improve livelihoods and resilience. Stakeholder based collaborative watershed management has become part of national policy in many countries. This includes India, Australia and North America [55–57] and more recently in Europe under the EU Water Framework Directive [58]. This is in line with the global recognition that ecosystem services are a lifeline for an number of traditional artisanal communities and marginalised groups around the world[12].

Natural resource management and restoration for disaster proofing

“Sustainable land management is an effective disaster risk reduction tool”[59] as per the IPCC special report entitled “Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation”. The role of management, or mismanagement of natural resources plays in vulnerabilities of local communities has been recognised by both the climate change community who are looking at adaptations to predicted changes and by disaster managers who are looking at hands on tools for mitigation and vulnerability reduction. In a broad review of literature Abramovits et.al., 2002[60] provide evidence that links deforestation and landslides, draining of wetlands and floods, loss of vegetation and droughts among others.

Reij et.al., 2010 and Reij, 2006[61, 62] describe initiatives taken by farmers in the Niger as a major,

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[9] http://www.unisdr.org/files/1037_hyogoframeworkforactionenglish.pdf

[10] http://unfccc.int/meetings/doha_nov_2012/meeting/6815.php

[11] http://www.thegef.org/gef/greenline/september-2011/terrafrica-partnership-sustainable-land-and

[12] http://www.dfid.gov.uk/What-we-do/Key-Issues/Climate-and-environment/.
For the international climate fund: http://www.dfid.gov.uk/Documents/publications1/uk-International-Climate-Fund-techncial-working-paper.pdf

[13] As part of its climate change action plan. http://www.afdb.org/en/.

[14] http://www.usaid.gov/what-we-do/environment-and-global-climate-change

[15] http://ec.europa.eu/europeaid/where/acp/regional-cooperation/water/second-water-facility_en.htm, http://ec.europa.eu/europeaid/work/procedures/financing/international_organisations/documents/guide_on_relations_with_ios+na+bc_en.doc

but unnoticed success story of private initiatives across entire farming communities. One of the triggers identified was a change in government policy which gave the communities ownership over trees. The strategy followed by the farmers appears to be centred around encouraging natural growth of trees and shrubs on cultivated fields. The area covered in Niger in this fashion has been estimated at three million hectares. They also record the success of farmers in the central plateau of Burkina Faso where agroforestry enabled farmers to extend and intensify production.

In another, more recent paper Sendzimir et.al., 2011[63] analysed the likely causes for the success of the Nigerian experience described earlier and further documented as A system termed as farmer-managed natural regeneration (FMNR) [64,65]. They use systems modelling and the three step conceptual framework developed by Frazer[66] and attribute this to institutional changes in governance, followed by changes in livelihood patterns which resulted in changes in the biophysical environment. They highlight the importance ownership over resources and of farmer experimentation as a source of innovative restoration strategies.

In a review of traditional farming communities Altieri et.al., 2008[67] note that traditional systems have evolved across many years of adaptation and resilience to stress. They argue that a range of adaptation strategies can be gleaned from these systems and utilised by farmers globally.

A study of extreme rainfall events influencing pastoral livelihoods in east Africa by Little et.al., 2001[68] showed that such events were not in the living memory of the majority, leaving them ill equipped to deal with the floods of 1997/98. They describe the common strategy of pastoralists to deal with a range of crisis as “mobility and the maintenance of resource access to both grazing and water and explain how climate related risk can be exacerbated by market and social conditions.

Recent publications from Save the Children USA/UK[69–72], cover various aspects of range-land management through community based structures and traditional knowledge systems. While largely based on the Ethiopian experience, they are among the few documents on pastoralists and pastoral systems and provide important insights into the socio-economic dynamics of these communities. These documents lay out the steps for “Participatory Rangeland Management” which is now part of the policy in Ethiopia. They also discuss the “options” of rangeland management, namely that of intensive, enclosed ranges with external inputs as opposed to traditional migratory ranging practices. Issues common to the project area are the changing market drivers - export versus subsistence, fragmentation of rangelands, lack of policy to protect traditional migratory routes and patterns, environmental and ecological consequences of enclosures and the impact of external aid as opposed to internal coping mechanisms of communities.

In a critical review of the World Bank policies in natural resources management[10] Bruce and Mearns, 2007, include a section on “experiments” with pastoralists in Africa. This report provides insights into the lessons learnt and new “negotiated-tenure” approaches that are being attempted along with various lessons learnt. A similarly critical paper, Gnomes, 2006[73], examines conflicts involving pastoralist communities and hydraulic projects and analyses the impact of these projects on customary resource management arrangement and the environment.

A recent report for Care International[8] summarises the issues faced by pastoralists in northern Somalia, Sool and Sanaag, in the context of changing productivities. It uses a mix of remote sensing (NDVI) and field measurements including socio-economic analysis. The report has interesting factual information about forage species, links to important sources of data. Mahmoud et.al., 2012, also use the delta approach to downscale the GCM to northern Somalia and Somaliland.

Riche.et.al., 2009[74], studied climate related vulnerabilities and adaptive capacities of communities in six settlements in Ethiopia, three of CARE initiated interventions in the Borana Administrative Zone and another three of Save the Children, UK interventions in Shinile region. They make a series of recommendations to the government, donors and civil society organisations in the region which include linking with institutions engaged in weather and climate change studies, building upon local knowledge and strategies for climate change adaptation and identifying linkages between climate change and livelihood strategies.

The FAO has repeatedly highlighted the role of watershed restoration and management of natural resources as a strategy for resilience building[16] . A policy brief by Bernoux et.al., 2011[75] stress the linkage between carbon sequestration and watershed restoration and how local vulnerabilities and resilience are tied to the status of land resources. They argue for long term investments in watershed restoration as an important strategy and the need for evolving mechanisms for sustaining these interventions through payments for ecosystem services.

Other publications cover related strategies including interventions to reduce soil erosion, increasing fuel-wood availability and supplementing fodder for livestock[76]. Adaptation options suggested include (extracted from table 3: A comprehensive adaptation options matrix for the pilot districts):

- Implement water runoff control to prevent soil erosion; Plant trees/hedges for protection of soil and conservation of moisture Implement in situ soil and moisture conservation techniques; assist houses in installing rain water collection tanks Use of animal manure in restoring soil fertility.
- Improve grazing management; better legislation for community grazing lands f urther study on local rangeland classification (a & b) to design strategy for optimal use of rangelands.
- Smaller –scale irrigation, water harvesting and watershed management.
- Promoting conservation agriculture that consists of Crop-Livestock i ntegration and agroforestry in smallholder sector
- Develop agroforestry models for mountains and lowlands – need to consider the criteria such as natural resources management (soil and water), enhancing livelihood opportunities by providing fodder and fruits and controlling soil erosion.

In Sudan, several communities have been involved in sustainable livelihoods and NRM as measures for resilience against climate change and related extreme events[77]. This pilot project was called the “Community-Based Rangeland Rehabilitation for Carbon Sequestration and Biodiversity” based in Gireighikh, Bara Province of North Kordofan State and funded by the United National Development Program, Global Environment Facility to the Sudanese government in 1995.

Jindal et.al., 2008[78] review 23 projects pertaining to carbon sequestration under the clean development mechanism (CDM) across 14 African countries, nine of which fall in East Africa (Kenya, Tanzania, and Uganda) . The projects fall under a period between 1992 and 1012. They found that afforestation activities increase incomes and stabilise the resource base. However, certain afforestation measures aimed solely at maximising sequestration advocate utilisation of fast growing exotic species which pose

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[16] For e.g.`http://www.fao.org/forestry/16639-064a7166b1dd027504bbfbb763878af99.pdf`

a real ecological danger. Furthermore, they found that unless these projects were implemented keeping in mind issues of control, access and existing tenure systems, they could result in exclusion of certain stakeholders from their benefits.

Climate change, vulnerabilities and adaptation

The repercussions of climate change on vulnerability are moderated through a number of filters. Among these are the social security system which can range from formal government and insurance systems to informal community and clan based arrangements. Economic and market networks also play an important role in the ability of communities to adjust to environmental hazards and extreme events. However, access to natural resources appears to be the primary mechanism as in the case of pastoralists in the eastern part of the Horn of Africa. The primary coping mechanisms here appears to lie in an alteration of resource use. Unfortunately some of these further degrade the natural resource base.

Prolonging the grazing period in a single location is one strategy which leads to overgrazing of pastures and consequent increase in unpalatable woody species[79] as well as erosion and termites as reported in Flintan et.al., 2011[80]. The other is the increase in charcoal production as an alternative income generation activity which is resulting in observable changes in tree cover[81]. Again the associated environmental issues include reduction of among the few sources of browsable biomass during extended periods of drought[82], increased erosion and micro-climatic changes.

There have been various studies on climate change and coping strategies adopted by communities. There is a growing body of literature that suggests that involving primary stakeholders in the design of strategies is necessary. This is because many effective natural resource management decisions are known to be based on experiential and adaptive learning processes[83]. Downing et.al., 1997[84] present an early review of climate change and argue for linking primary stakeholders in the design in adaptation strategies, particularly to understand their vulnerabilities, constraints and how they manage their natural resource base. An even earlier paper by Ellis et.al., 1988[?], advises that development policies be reoriented to “build on and facilitate traditional pastoralist strategies”. They argue that pastoral systems are ecologically non-equilibria yet persistent systems and attempts to stabilise them are likely to fail. Clearly this advise was unheeded[85].

[86]focus on institutional mechanisms and international and national action on climate change and policies for climate change adaptation and more localised adaptations by communities, in the absence of government interventions. A particular reference is made to the pastoralists in West Africal Sahel who have adapted to a 25% reduction in precipitation due to the inherent resilience of their migratory livelihoods.

In their background paper on resilience for the world summit on sustainable development. Folke et.al., 2002[87] argue in favour of building socio-ecological systems which adopt scenario building and adaptive management strategies to control change in natural systems. They find that rigid systems relying on monoculture are less reliant than flexible approaches to natural resource management, giving the case of the EU watershed management directive as an example. A similar theme is pursued by Jones et.al., 2010[88] who studied how different disaster risk reduction, social protection and livelihood interventions could help communities adapt to climate change. They note that climate change will add to the complexity of meeting development challenges in the poor and underdeveloped regions of the world. They cite various natural resource management strategies such as participatory reforestation, range land management and vegetation regeneration as a means of building response capacity to climate change. NRM is also shown to be a central component of disaster risk reduction and livelihood promotion for coping with the adverse effects of climate change.

Access to resources, social support systems and cultural beliefs have a defining impact on livelihood strategies pursued by communities. Nyasimi et.al., 2007[89] compare the manner in which livelihood diversification has been pursued by two neighbouring groups in Kenya - The Luo people of Kanyibana village and the Kipsigis in Ainamoi village and find that the lack of resources has forced the former to diversify into risky and potentially unsustainable rural labour markets while the latter has invested in food processing and markets by relying on cross boundary cultural ties and effective land management as a starting point.

There have been a number of papers which have taken downscaled or regional climate models, linked them to local models for land use and hydrology and built scenarios of different climate change predictions.

The basic concern about climate change is that it may affect currently productive ecosystems in ways that breaks ecological function, leading to a dysfunctional and degraded resource base on which communities continue to depend. Dougill et.al., 2010[90] evaluate the abilities of agro-ecosystems, communities, and institutions to adapt to climate change, more specifically drought based on ecological and participatory research on pastoralist communities from the Kalahari in Botswana. Their focus is on the possibility that some of these ecosystems may cease to function. Using a systems modelling approach to test various scenarios, they conclude that by sharing knowledge of appropriate land management, private and communal land managers can reduce system vulnerability and increase incomes.

Moore et.al., 2012[91] linked regional level climate change models to estimate the spatial variability of crop yields in East Africa. Among their major findings were that land use and land cover have a major effect on yield often driving the crop model results as significantly as green house gases. They also noted a high variability in simulated yield changes across the study region. This was partly explained by high local variation in other parameters such as soil types. They argued that linking regionalised climate models to process-driven crop yield models can provide insights into food production risk.

Jones and Thorton, 2009[54] predict that the predicted drop in agricultural production of 10-20% in Africa will push local communities towards pastoralism as an adaptation strategy. Using downscaled climate models, they predict that climate change impacts in marginal cropping areas will be high in terms of productivities and populations in remote marginal areas will be disproportionately affected.

Summary

Africa is expected to be among the worst affected regions of the world with respect to climate change. Broad predictions of the IPCC[17] suggest a high likelihood of warming exceeding global annual means throughout the continent and in all seasons. Rainfall is expected to decrease across the continent, except Eastern Africa, and the Sahel where predictions are inconclusive. This is expected to have serious repercussions on food security, health, increased water stress and conflicts with a 5 to 8% increase in arid and semi-arid lands[92].

Even in scenarios of increased precipitation, there is nearly universal agreement that variability of rainfall and temperatures will increase. The increase in extreme rainfall events followed by prolonged

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[17] `http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch11s11-2.html`

periods of dryness interspersed with peaks in temperature can tip the fragile pastoralist regions in the Horn of Africa and Sahel into a downward spiral of degradation and desertification. Community based watershed restoration becomes a compelling strategy in this context for a number of reasons. It establishes locally managed mechanisms to contain erosion and store water for longer periods, in the soil and ground and in artificial water harvesting structures. It attempts to optimise biomass production in these improved conditions thereby prolonging the growing season for fodder and forage. Afforestation and agro-forestry interventions stem the destructive coping strategy of charcoal by providing more fuel and forage during the dry months.

Controlling runoff and erosion, particularly when rainfall is expected to increase in variability and intensity, is essential. A series of small water harvesting and flow control structures can hold back water for ground water recharge, improving local soil moisture and the drawing out the period of moisture retention to partially compensate for prolonged dry spells which are likely to follow extreme precipitation events. Physical structures, are one of the components of watershed restoration. This has to be supplemented by biological interventions through re-introduction of appropriate fodder, forage and fuelwood species and agro-forestry species.

Experiences across the world, especially Africa highlight the need for suitable institutional structures to manage natural resources. Lessons from pastoralist communities emphasise the need for management arrangements to evolve from the grassroots and take into account the flexible and overlapping boundaries and jurisdictions. This will mould the nature of interventions and strategies pursued. Important lessons can be drawn from experiences in Somalia, Ethiopia and Kenya cited earlier.

Natural resource management cannot serve as a stand alone disaster proofing strategy. It needs to be supported by governance mechanisms for social protection and institutional frameworks at the policy level which facilitate and empower communities to take over the management of their resources. Further, local management need to be socially and culturally acceptable, a lessons that has been repeated with pastoral communities in Africa. Capacity building is another component which cannot be ignored as it ensures innovation and knowledge building leading to adaptive management.

References

[1] Hulme, M., Doherty, R., Ngara, T., New, M. & Lister, D. African climate change: 1900-2100. *Climate research* **17**, 145–168 (2001). URL `http://isites.harvard.edu/fs/docs/icb.topic871786.files/c017p145.pdf`.

[2] Boko, M. *et al.* Africa. In Parry, M. L., Canziani, O. F., Palutikof, J. P., van der Linden, P. J. & Hanson, C. E. (eds.) *Climate Change 2007Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Intergovernmental Panel on Climate Change, 2007). URL `http://www.ipcc-wg2.gov/AR4/website/fi.pdf`.

[3] Paeth, H., Born, K., Girmes, R., Podzun, R. & Jacob, D. Regional climate change in tropical and northern africa due to greenhouse forcing and land use changes. *Journal of Climate* **22**, 114–132 (2009). URL `http://journals.ametsoc.org/doi/abs/10.1175/2008JCLI2390.1`.

[4] Thornton, P. K. *et al.* Climate change and poverty in africa: Mapping hotspots of vulnerability. *African Journal of Agricultural and Resource Economics* **2**, 24–44 (2008). URL `http://lib.icimod.org/record/13357/files/1621.pdf`.

[5] Christensen, J. H. *et al.* Regional climate projections. In *Climate Change, 2007: The Physical Science Basis. Contribution of Working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, University Press, Cambridge, Chapter 11*, 847–940 (2007). URL `http://epic.awi.de/17617/`.

[6] Giannini, A., Biasutti, M., Held, I. M. & Sobel, A. H. A global perspective on african climate. *Climatic Change* **90**, 359–383 (2008). URL `http://www.springerlink.com/index/415661jkrrxqqx28.pdf`.

[7] Schreck, C. J. & Semazzi, F. H. M. Variability of the recent climate of eastern africa. *International Journal of Climatology* **24**, 681–701 (2004). URL `http://onlinelibrary.wiley.com/doi/10.1002/joc.1019/abstract`.

[8] Mahmoud, H. A., Omuto, C. T. & Said, M. Y. Toward sustainable pastoralism in sool and sanaag, northern somalia. Tech. Rep., Care (2012).

[9] Secretariat of the Convention on Biological Diversity. The convention on biological diversity. http://www.cbd.int/ (2012). URL `http://www.cbd.int/`.

[10] Bruce, J. W. & Mearns, R. Natural resource management and land policy in developing countries. *World Bank* **18**, 22 (2007).

[11] World Resources Institute. World resources 2005: The wealth of the poor - managing ecosystems to fight poverty. Tech. Rep., World Resources Institute (WRI) in collaboration with United Nations Development Programme, United Nations Environment Programme and World Bank, Washington, DC (2005). ISBN 1-56973-582-4.

[12] Millenium Ecosystem Assessment. Ecosystems and human well-being: general synthesis. *World Resources Institute, Washington, DC* (2005).

[13] Millenium Ecosystem Assessment. *Our human planet: Summary for decision-makers* (Island Press, 2005).

[14] Tallis, H., Kareiva, P., Marvier, M. & Chang, A. An ecosystem services framework to support both practical conservation and economic development. *Proceedings of the National Academy of Sciences* **105**, 9457 (2008).

[15] Brauman, K., Daily, G., Duarte, T. & Mooney, H. The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annu. Rev. Environ. Resour.* **32**, 67–98 (2007).

[16] Costanza, R. *et al.* The value of the world's ecosystem services and natural capital. *Nature* **387**, 253–260 (1997).

[17] Wallace, K. J. Classification of ecosystem services: problems and solutions. *Biological Conservation* **139**, 235–246 (2007).

[18] Daily, G. C. & Matson, P. A. Ecosystem services: From theory to implementation. *Proceedings of the National Academy of Sciences* **105**, 9455 –9456 (2008). URL `http://www.pnas.org/content/105/28/9455.abstract`.

[19] Daily, G. C. *et al.* Ecosystem services in decision making: time to deliver. *Frontiers in Ecology and the Environment* **7**, 21–28 (2009).

[20] De Groot, R., Alkemade, R., Braat, L., Hein, L. & Willemen, L. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecological Complexity* **7**, 260–272 (2010).

[21] Loomis, J., Kent, P., Strange, L., Fausch, K. & Covich, A. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. *Ecological Economics* **33**, 103–117 (2000).

[22] Pires, M. Watershed protection for a world city: the case of new york. *Land Use Policy* **21**, 161–175 (2004).

[23] Waage, S., Armstrong, K. & Hwang, L. New business decision - making aids in an era of complexity, scrutiny, and uncertainty. Tech. Rep. (2011). URL `http://www.bsr.org`.

[24] Chen, H., Xu, C. Y. & Guo, S. Comparison and evaluation of multiple GCMs, statistical downscaling and hydrological models in the study of climate change impacts on runoff. *Journal of Hydrology* **434**, 36–45 (2012). URL `http://www.sciencedirect.com/science/article/pii/S0022169412001539`.

[25] Surfleet, C. G., Tullos, D., Chang, H. & Jung, I. W. Selection of hydrologic modeling approaches for climate change assessment; a comparison of model scale and structures. *Journal of Hydrology* (2012). URL `http://www.sciencedirect.com/science/article/pii/S0022169412005884`.

[26] Xu, C. Climate change and hydrologic models: A review of existing gaps and recent research developments. *Water Resources Management* **13**, 369–382 (1999). URL `http://www.springerlink.com/index/v187686x63176536.pdf`.

[27] Trenberth, K. E. & Asrar, G. R. Challenges and opportunities in water cycle research: WCRP contributions (2012). URL `http://climatemodeling.science.energy.gov/sites/default/files/Water_WCRP_ISSI.v3.pdf`.

[28] Trenberth, K. E. Conceptual framework for changes of extremes of the hydrological cycle with climate change. *Climatic Change* **42**, 327–339 (1999). URL `http://www.springerlink.com/index/w26v83t3k85241m1.pdf`.

[29] Bennett, E. M. *et al.* Why global scenarios need ecology. *Frontiers in Ecology and the Environment* **1**, 322–329 (2003). URL `http://www.esajournals.org/doi/pdf/10.1890/1540-9295(2003)001[0322:WGSNE]2.0.CO;2`.

[30] Nakicenovic, N. *et al. Special Report on Emissions Scenarios : a special report of Working Group III of the Intergovernmental Panel on Climate Change* (2000). URL `http://www.osti.gov/energycitations/servlets/purl/15009867-Kv00FB/native/`.

[31] Pachauri, R. K. & Reisinger, A. *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (Intergovernmental Panel on Climate Change, 2007).

[32] Solomon, S. *et al.* (eds.) *Climate change 2007: the physical science basis* (Intergovernmental Panel on Climate Change, 2007). URL `http://www.slvwd.com/agendas/Full/2007/06-07-07/Item%2010b.pdf`.

[33] Maraun, D. *et al.* Precipitation downscaling under climate change: Recent developments to bridge the gap between dynamical models and the end user. *Reviews of Geophysics* **48**, RG3003 (2010). URL `http://eprints.uni-kiel.de/11662/`.

[34] Fowler, H. J., Blenkinsop, S. & Tebaldi, C. Linking climate change modelling to impacts studies: recent advances in downscaling techniques for hydrological modelling. *International Journal of Climatology* **27**, 1547–1578 (2007). URL `http://onlinelibrary.wiley.com/doi/10.1002/joc.1556/abstract`.

[35] Graham, L. P., Andréasson, J. & Carlsson, B. Assessing climate change impacts on hydrology from an ensemble of regional climate models, model scales and linking methods–a case study on the lule river basin. *Climatic Change* **81**, 293–307 (2007). URL `http://www.springerlink.com/index/D263335641074782.pdf`.

[36] Graham, L. P., Hagemann, S., Jaun, S. & Beniston, M. On interpreting hydrological change from regional climate models. *Climatic Change* **81**, 97–122 (2007). URL `http://www.springerlink.com/index/BL57954080540651.pdf`.

[37] Tripathi, M. P., Panda, R. K. & Raghuwanshi, N. S. Identification and prioritisation of critical subwatersheds for soil conservation management using the SWAT model. *Biosystems Engineering* **85**, 365–379 (2003).

[38] Cullum, R., Knight, S., Cooper, C. & Smith, S. Combined effects of best management practices on water quality in oxbow lakes from agricultural watersheds. *Soil and Tillage Research* **90**, 212–221 (2006). URL `http://ddr.nal.usda.gov/dspace/bitstream/10113/7733/1/IND43870404.pdf`.

[39] Setegn, S. G., Srinivasan, R. & Dargahi, B. Hydrological modelling in the lake tana basin, ethiopia using SWAT model. *The Open Hydrology Journal* **2**, 49–62 (2008).

[40] Tobin, K. J. & Bennett, M. E. Using SWAT to model streamflow in two river basins with ground and satellite precipitation data. *Journal of the American Water Resources Association* **45**, 253–271 (2009).

[41] Cao, W., Bowden, W., Davie, T. & Fenemor, A. Modelling impacts of land cover change on critical water resources in the motueka river catchment, new zealand. *Water Resources Management* **23**, 137–151 (2009). URL `http://dx.doi.org/10.1007/s11269-008-9268-2`.

[42] Bonell, M. *et al.* The impact of forest use and reforestation on soil hydraulic conductivity in the western ghats of india: Implications for surface and sub-surface hydrology. *Journal of Hydrology* **391**, 47–62 (2010). URL `http://www.sciencedirect.com/science/article/B6V6C-50H1WWH-3/2/67f19c35ebe6bcd0b0b0ef565274324a`.

[43] Agarwal, C., Green, G. M., Grove, J. M., Evans, T. P. & Schweik, C. M. A review and assessment of land-use change models: dynamics of space, time, and human choice. General Technical Report NE-297, USDA Forest Service. Center for the Study of Institutions, Population, and Environmental Change, Indiana University, Bloomington (IN) and USDA Forest Service, Northeastern Research Station, South Burlington (VT) (2001).

[44] Bruijnzeel, L. A. Hydrological functions of tropical forests: not seeing the soil for the trees? *Agriculture, Ecosystems & Environment* **104**, 185–228 (2004). URL `http://www.sciencedirect.com/science/article/B6T3Y-4BY3RYK-1/2/4b73e37c7c7b1e1376531fedc3d6a431`.

[45] Krishnaswamy, J., Lele, S. & Jayakumar, R. (eds.) *Hydrology and Watershed Services in the Western Ghats of India: Effects of land use and land cover change* (Tata McGraw-Hill, New Delhi, India, 2006), 1 edn.

[46] Neitsch, S. L., Arnold, J. G., Kiniry, J. R., Williams, J. R. & King, K. W. *Soil And Water Assessment Tool, Theoretical Documentation*, vol. Version 2000 (Grassland, Soil And Water Research Laboratory Agricultural Research Service 808 East Blackland Road Temple, Texas 76502 Blackland Research Center Texas Agricultural Experiment Station 720 East Blackland Road Temple, Texas 76502, 2002).

[47] Borah, D. K. & Bera, M. Watershed-scale hydrologic and nonpoint-source pollution models: Review of applications. *Transactions of the ASAE* **47**, 789–803 (2004).

[48] Chekol, D. A., Tischbein, B., Eggers, H. & Vlek, P. *Application of SWAT for Assessment of Spatial Distribution of Water Resources and Analyzing Impact of Different Land Management Practices on*

Soil Erosion in Upper Awash River Basin Watershed (FWU Water Resources Publications. Volume, 2007).

[49] Van Liew, M. W., Veith, T. L., Bosch, D. D. & Arnold, J. G. Suitability of SWAT for the conservation effects assessment project: Comparison on USDA agricultural research service watersheds. *Journal of Hydrologic Engineering* **12**, 173 (2007).

[50] Gassman, P. W., Reyes, M. R., Green, C. H. & Arnold, J. G. The soil and water assessment tool: Historical development, applications, and future research directions. *Trans. ASABE* **50**, 1211–1250 (2007).

[51] Rao, M. *et al.* A web-based GIS decision support system for managing and planning USDA's conservation reserve program (CRP). *Environmental Modelling and Software* **22**, 1270–1280 (2007).

[52] Huang, P. H., Tsai, J. S. & Lin, W. T. Using multiple-criteria decision-making techniques for eco-environmental vulnerability assessment: a case study on the chi-jia-wan stream watershed, taiwan. *Environmental monitoring and assessment* **168**, 141–158 (2010).

[53] Montgomery, D. R., Grant, G. E. & Sullivan, K. Watershed analysis as a framework for implementing ecosystem management. *Water Resources Bulletin* **31**, 369–386 (1995).

[54] Jones, P. G. & Thornton, P. K. Croppers to livestock keepers: livelihood transitions to 2050 in africa due to climate change. *environmental science & policy* **12**, 427–437 (2009). URL `http://www.sciencedirect.com/science/article/pii/S1462901108000944`.

[55] Government of India. Report of the technical committee on drought prone areas programme and desert development programme. Tech. Rep., Ministry of Rural Development, Government of India (1994). URL `http://dolr.nic.in/TechCommitteeReport1994/TechCommitteeReport1994.htm`.

[56] Curtis, A., Byron, I. & MacKay, J. Integrating socio-economic and biophysical data to underpin collaborative watershed management. *Journal of the American Water Resources Association* **41**, 549–563 (2005).

[57] Ferreyra, C. & Beard, P. Participatory evaluation of collaborative and integrated water management: Insights from the field. *Journal of Environmental Planning and Management* **50**, 271–296 (2007).

[58] Bruen, M. Systems analysis? a new paradigm and decision support tools for the water framework directive. *Hydrology and Earth System Sciences* **12**, 739–749 (2008).

[59] Field, C. B. *et al.* Managing the risks from climate extremes at the local level. In *Managing the risks of extreme events and disasters to advance climate change adaptation* (A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, UK, and New York, NY, USA, 2012). URL `http://www.lavoisier.fr/livre/notice.asp?id=RROWLOA3AOXOWW`.

[60] Abramovitz, J. *et al.* Adapting to climate change: Natural resource management and vulnerability reduction. *World Conservation Union–IUCN, Worldwatch Institute, International Institute for Sustainable Development–IISD, Stockholm Environment Institute/Boston*

(2002). URL http://www.start.org/Program/advanced_institute3_web/p3_documents_folder/Abramavitz_etal.pdf.

[61] Reij, C., Tappan, G. & Smale, M. Agroenvironmental transformation in the sahel: another kind of “Green revolution”. *Proven Successes in Agricultural Development* 161 (2010). URL http://books.google.com/books?hl=en&lr=&id=zBTqydfKOeoC&oi=fnd&pg=PA161&dq=reij+2005+africa&ots=cnMtplktfO&sig=DT-TRwJ7Xv_xbBHJhosQJAoYa58.

[62] Reij, C. More success stories in africa’s drylands than often assumed. In *presentation at Network of Farmers’ and Agricultural Producers’ Organisations of West Africa (ROPPA) Forum on Food Sovereignty*, 7–10 (2006). URL http://www.roppa.info/IMG/pdf/More_success_stories_in_Africa_Reij_Chris.pdf.

[63] Sendzimir, J., Reij, C. P. & Magnuszewski, P. Rebuilding resilience in the sahel: regreening in the maradi and zinder regions of niger. *Ecology and Society* **16**, 1 (2011). URL http://focus.wpengine.netdna-cdn.com/wp-content/uploads/2012/07/Rebuilding-resilience-in-the-Sahel1.pdf.

[64] Bayala, J., Kalinganire, A., Tchoundjeu, Z., Sinclair, F. & Garrity, D. Conservation agriculture with trees in the west african sahel–a review. *ICRAF Occasional Paper* **14** (2011). URL http://www.worldagroforestry.org/downloads/publications/PDFS/OP17114.PDF.

[65] Cunningham, P. J. & Abasse, T. Annexe 10: Reforesting the sahel: Farmer managed natural regeneration. *situation actuelle et perspectives* (2005). URL http://www.worldagroforestry.org/downloads/publications/PDFs/WP13809.PDF#page=81.

[66] Fraser, E. D. G. Travelling in antique lands: using past famines to develop an adaptability/resilience framework to identify food systems vulnerable to climate change. *Climatic Change* **83**, 495–514 (2007). URL http://www.springerlink.com/index/R26717H0KQ341385.pdf.

[67] Altieri, M. A. & Koohafkan, P. *Enduring farms: Climate change, smallholders and traditional farming communities* (Third World Network (TWN), 2008). URL http://sa.indiaenvironmentportal.org.in/files/Enduring_Farms.pdf.

[68] Little, P., Negatu, W. & Ericksen, P. Climate-induced vulnerability and pastoralist livestock marketing chains in southern ethiopia and northeastern kenya (2011). URL http://lcccrsp.org/wp-content/uploads/2011/09/Little_P_Africa_LTRP.pdf.

[69] Flintan, F. & Cullis, A. Introductory guidelines to participatory rangeland management in pastoral areas. *Save the Children USA. Addis Ababa, Ethiopia. www. elmt-relpa. org/aesito/HOAPN* (2010). URL http://www.disasterriskreduction.net/fileadmin/user_upload/drought/docs/Participatory%20range%20land%20management%20RM%20Guideline%20(4).pdf.

[70] Flintan, F. The political economy of land reform in pastoral areas: Lessons from africa, implications for ethiopia (2011). URL http://www.celep.info/wp-content/uploads/downloads/2011/04/Political-economy-of-Land1.pdf.

[71] Flintan, F., Tache, B. & Eid, A. Rangeland fragmentation in traditional grazing areas and its impact on drought resilience of pastoral communities: Lessons from borana, oromia and harshin, somali regional states, ethiopia (2011). URL `http://www.disasterriskreduction.net/fileadmin/user_upload/drought/docs/Ethiopia%20Land%20Fragmentation%20Report_FINAL%207%20feb%202012.pdf`.

[72] Flintan, F. Making rangelands secure: past experience and future options. *ILC, Rome* (2012). URL `http://ww.landportal.info/sites/default/files/rangelands_bookcover_30.1.121.pdf`.

[73] Gomes, N. Access to water, pastoral resource management and pastoralists' livelihoods: Lessons learned from water development in selected areas of eastern africa (Kenya, ethiopia, somalia). *FAO LSP WP* **26** (2006). URL `http://www.mbali.info/doc243.htm`.

[74] Riché, B., Hachileka, E., Awuor, C. B. & Hammill, A. Climate-related vulnerability and adaptive capacity in ethiopia's borana and somali communities. *Manitoba: International Institute for Sustainable Development* (2009). URL `http://typo3.fao.org/fileadmin/user_upload/drought/docs/7_Climate_Change_study,_Full_Assessment_Report_FINAL.pdf`.

[75] Bernoux, M., Bockel, L., Rioux, J., Tinlot, M. & Braimoh, A. K. Carbon sequestration as an integral part of watershed management strategies to address climate change issues. Polycy Brief (2011). URL `http://www.fao.org/fileadmin/templates/ex_act/pdf/Policy_briefs/Carbon_watershed_management_July_2011.pdf`.

[76] Dejene, A., Midgley, S., Marake, M. V. & Ramasamy, S. Strengthening capacity for climate change adaptation in agriculture: Experience and lessons from lesotho. Tech. Rep. 18, FAO (2011). URL `http://www.fao.org/docrep/014/i2228e/i2228e00.pdf`.

[77] Elasha, B. O., Elhassan, N. G., Ahmed, H. & Zakieldin, S. Sustainable livelihood approach for assessing community resilience to climate change: case studies from sudan. Tech. Rep., AIACC Working Paper (2005). URL `http://www.iflea.org/pdf/AIACC_WP_No017.pdf`.

[78] Jindal, R., Swallow, B. & Kerr, J. Forestry-based carbon sequestration projects in africa: Potential benefits and challenges. *Natural Resources Forum* **32**, 116–130 (2008). URL `http://onlinelibrary.wiley.com/doi/10.1111/j.1477-8947.2008.00176.x/full`.

[79] Dalle, G., Maass, B. L. & Isselstein, J. Encroachment of woody plants and its impact on pastoral livestock production in the borana lowlands, southern oromia, ethiopia. *African Journal of Ecology* **44**, 237–246 (2006). URL `http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2028.2006.00638.x/full`.

[80] Flintan, F., Tache, B. & Eid, A. Rangeland fragmentation in traditional grazing areas and its impact on drought resilience of pastoral communities: Lessons from borana, oromia and harshin, somali regional states, ethiopia (2011). URL `http://www.disasterriskreduction.net/fileadmin/user_upload/drought/`

docs/Ethiopia%20Land%20Fragmentation%20Report_FINAL%207%20feb%202012.pdf.

[81] Oduori, S. M., Rembold, F., Abdulle, O. H. & Vargas, R. Assessment of charcoal driven deforestation rates in a fragile rangeland environment in north eastern somalia using very high resolution imagery. *Journal of Arid Environments* **75**, 1173–1181 (2011). URL http://www.sciencedirect.com/science/article/pii/S0140196311001558.

[82] Abule, E., Snyman, H. A. & Smit, G. N. Rangeland evaluation in the middle awash valley of ethiopia: II. woody vegetation. *Journal of arid environments* **70**, 272–292 (2007). URL http://www.sciencedirect.com/science/article/pii/S0140196307000468.

[83] Allan, C., Curtis, A., Stankey, G. & Shindler, B. Adaptive management and watersheds: A social science perspective1. *JAWRA Journal of the American Water Resources Association* **44**, 166–174 (2008).

[84] Downing, T. E., Ringius, L., Hulme, M. & Waughray, D. Adapting to climate change in africa. *Mitigation and adaptation strategies for global change* **2**, 19–44 (1997). URL http://www.springerlink.com/index/U2J72L0244J1M77Q.pdf.

[85] Bromley, D. W. & Cernea, M. M. *The management of common property natural resources: Some conceptual and operational fallacies*, vol. 57 (World Bank Publications, 1989). URL http://books.google.com/books?hl=en&lr=&id=XHspFfKLZ8wC&oi=fnd&pg=PA1&dq=somalia+watershed+management&ots=9PG0O9-4aF&sig=y-leTGOqrDQZQYtk9beJ78sbmSw.

[86] Adger, W. N., Huq, S., Brown, K., Conway, D. & Hulme, M. Adaptation to climate change in the developing world. *Progress in development studies* **3**, 179–195 (2003). URL http://pdj.sagepub.com/content/3/3/179.short.

[87] Folke, C. *et al.* Resilience and sustainable development: building adaptive capacity in a world of transformations. *AMBIO: A Journal of the Human Environment* **31**, 437–440 (2002). URL http://www.bioone.org/doi/abs/10.1579/0044-7447-31.5.437.

[88] Jones, L. *et al.* Responding to a changing climate: Exploring how disaster risk reduction, social protection and livelihoods approaches promote features of adaptive capacity (2010). URL http://dspace.cigilibrary.org/jspui/handle/123456789/29476.

[89] Nyasimi, M. *et al.* Differentiating livelihood strategies among the luo and kipsigis people in western kenya. *Journal of Ecological Anthropology* **11**, 44 (2007). URL http://web.mnstate.edu/robertsb/307/ANTH%20307/Articles/Nyasimi.pdf.

[90] Dougill, A. J., Fraser, E. D. G. & Reed, M. S. Anticipating vulnerability to climate change in dryland pastoral systems: using dynamic systems models for the kalahari. *Ecology and Society* **15**, 17 (2010). URL http://www.cccep.ac.uk/Publications/Working-papers/Papers/30-39/WP32-climate-change-dryland.pdf.

[91] Moore, N. *et al.* East african food security as influenced by future climate change and land use change at local to regional scales. *Climatic change* **110**, 823–844 (2012). URL `http://www.springerlink.com/index/E117658Q5348Q564.pdf`.

[92] Boko, M. *et al.* Africa: climate change—adaptation and vulnerability. *Contribution of Working Group II to the IV Assessment Report of the IPCC Panel on Climate Change, Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds). Cambridge University Press: Cambridge* (2007). URL `http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter9.pdf`.

[93] Ruosteenoja, K., Carter, T. R., Jylhä, K. & Tuomenvirta, H. *Future climate in world regions: an intercomparison of model-based projections for the new IPCC emissions scenarios*, vol. 644 (Finnish Environment Institute Helsinki, 2003). URL `http://mms.dkrz.de/pdf/klimadaten/static/IPCC_DDC/html/sres/scatter_plots/scatter_plot_report.pdf`.

[94] Waters-Bayer, A. & Bayer, W. Planning with pastoralists: PRA and more. *A review of methods focused on Africa. Eschborn: GTZ, OE* **422**, 153 (1994). URL `http://www2.gtz.de/dokumente/bib/95-0400.pdf`.

[95] Bayer, W. & Waters-Bayer, A. Participatory monitoring and evaluation (PM&E) with pastoralists. *Deutsche Gessellschaft fu «r Technische Zusammenarbeit (GTZ), Eschborn* (2002). URL `http://www.giz.de/Themen/de/dokumente/en-SVMP-waters-bayer-2002.pdf`.

[96] Tempia, S. *et al.* Mapping cattle trade routes in southern somalia: a method for mobile livestock keeping systems. *Revue scientifique et technique* **29**, 485 (2010). URL `http://sahsp.info/SiteContent/Documents/Others/Cattle%20Trade%20Routes.pdf`.

[97] Sedogo, L. G. & Groten, S. M. E. Integration of local participatory and regional planning: A GIS data aggregation procedure. *GeoJournal* **56**, 69–82 (2002). URL `http://www.springerlink.com/index/J227411826525033.pdf`.

[98] Bhalla, R. S. & Benjamin Larroquette. *Field Methods in Participatory GIS* (Foundation for Ecological Research, Advocacy and Learning, Pondicherry, India, 2004), 1 edn. URL `http://www.feralindia.org/booklets/pgis.pdf`.

[99] McCall, M. K. & Morelia, M. pgis-psp–lsk. *Human Ecology* **30**, 215–226 (2010). URL `http://ppgis.iapad.org/ppgis/pdf/PGIS_PSP_LSK_Biblio_may_2010.pdf`.

Appendix

A Climate change scenarios

The following is a summary of various emission scenarios described by Nakicenovic et.al., 2000[30]. These scenarios are the basic assumptions made by atmosphere-ocean global circulation models as well as regional climate models (from Ruosteenoja, K., T. R. Carter, K. Jylhä, and H. Tuomenvirta. Future Climate in World Regions: An Intercomparison of Model-based Projections for the New IPCC Emissions Scenarios. Vol. 644. Finnish Environment Institute Helsinki, 2003. `http://mms.dkrz.de/pdf/klimadaten/static/IPCC_DDC/html/sres/scatter_plots/scatter_plot_report.pdf`. [93]).

A1: A future world of very rapid economic growth, low population growth and rapid introduction of new and more efficient technology. Major underlying themes are economic and cultural convergence and capacity building, with a substantial reduction in regional differences in per capita income. In this world, people pursue personal wealth rather than environmental quality.

A2: A differentiated world with strong regional cultural identities, high population growth, slow economic development.

B1: A convergent world with rapid change in economic structures, social and environmental sustainability, clean technologies, dematerialization and improving equity.

B2: A diverse and heterogeneous world with local solutions to achieving economic, social, and environmental sustainability. Less rapid economic growth, more diverse technological change based on community initiative and social innovation to find local, rather than global solutions.

Overlayed on these are three technological options:

A1FI (fossil intensive)

A1T (predominantly non-fossil)

A1B (balanced across energy sources).

In descending order of radiative forcing by 2100, the illustrative scenarios rank: A1FI, A2, A1B, B2, A1T, B1.

B Other methodology papers

Waters-Bayer and Bayer, 1994[94] wrote one of the most cited participatory methods report in this sector entitled "Planning with pastoralists: PRA and more", A review of methods focused on Africa. This 100+ page report attempts to bridge the gap in participatory research, which had been concentrating on sedentarised livelihoods. The report covers a wide range of methods tuned to pastoral livelihoods and provides an annotated bibliography for further reading.

Bayer and Waters-Bayer, 2008[95], as an update to their oft cited work, provide a review of largely grey literature on participatory monitoring and evaluation with pastoralists. They analyse the risks and opportunities provided by participatory methods and summarise experiences of various projects and studies. The document ends with a useful bibliography of participatory methods.

Tempia et.al., 2010[96] present an interesting application of using GPS units and participant based data collection for quantitative and spatially explicit data on movement patterns of pastoralists. This paper provides a good insight into designing participatory research methods which could substantially increase our know how on pastoralist migration and movement.

Thorton et.al., 2008[4]used a range of spatially explicit secondary data and climate models to map out “hot spots” of high vulnerability in Sub-Saharan Africa. The paper presents an interesting range of data in terms of sources and subjects. While there is room for “ground truthing” the findings, this is a good initial study or scoping study for continental scale vulnerability assessments.

Elasha et.al., 2005[77] present an adaptation of the DFID sustainable livelihoods framework in the context of community resilience and adaptability to climate change including increased temperature, variability and likely decrease rainfall. The provide detailed frameworks and questionnaires used for their study.

Riche.et.al., 2009[74] provide a methodological framework for their study which uses a variety of participatory methods for assessing vulnerability to climate change and adaptability of communities. This includes field guides for participatory exercises including a rain calendar, vulnerability matrix and detailed format for field reports.

Sedogo and Groten, 2002[97], Bhalla and Larooquette, 2004[98], and McCal and Morelia, 2010[99] demonstrate various advantages of combining GIS, remote sensing and participatory mapping methods. These techniques facilitate collection of bottom up spatially and temporally explicit maps for resource utilisation. Once on a GIS, they can easily be integrated with other GIS and remote sensing based data including hydraulic and landuse change models which are linked to downscaled climate change predictions.