Slow Onset Events

Technical Guide: Desertification

Addressing complex challenges for a sustainable future

Bettina Koelle (1), Marioldy Sanchez Santivanez (2), Noel Oettle (3), Manon Ebel (1), Emmanuel Seck (4)

(1) *Red Cross Red Crescent Climate Centre – Netherlands/ South Africa /Canada*
(2) *AIDER – Peru*
(3) *INDIGO development & Change - South Africa*
(4) *ENDA Energie, Senegal*

Figure 1: Climate Change and desertification in a systems perspective. Artist: Kuper.

version 1_3 - 15 August 2024 (2nd draft for comments)

Definitions

Adaptation: The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects. (IPCC 2018)

Incremental adaptation: Adaptation actions where the central aim is to maintain the essence and integrity of a system or process at a given scale. (IPCC 2018)

Transformational adaptation: Adaptation that changes the fundamental attributes of a system in response to climate and its effects. (IPCC 2018)

Adaptive Management: A process of iteratively planning, implementing, and modifying strategies for managing resources in the face of uncertainty and change. Adaptive management involves adjusting approaches in response to observations of their effect and changes in the system brought on by resulting feedback effects and other variables. (IPCC WGII AR5 2018)

Cascading impacts: Cascading impacts from extreme weather/climate events occur when an extreme hazard generates a sequence of secondary events in natural and human systems that result in physical, natural, social or economic disruption, whereby the resulting impact is significantly larger than the initial impact. Cascading impacts are complex and multi-dimensional, and are associated more with the magnitude of vulnerability than with that of the hazard. (IPCC 2019)

Compound events: Compound events refer to the combination of multiple drivers and/or hazards that contribute to societal or environmental risks. (IPCC 2019)

Desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities (UNCCD 1994)

Drought means the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems (UNCCD 1994)

Meteorological drought occurs when the precipitation for a given period is lower by some predefined amount from the long-term mean amount of precipitation an area receives (Wilhite, 2002).

Agricultural drought relates various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, etc. (IPCC, 2021).

Ecological drought is a prolonged and widespread deficit in naturally available water supplies that creates multiple stresses across ecosystems (IPCC, 2021).

Hydrological drought occurs when deficits in surface and sub- surface water supplies (including streams and lakes) are below a defined threshold (Wilhite, 2002).

Socio-economic drought occurs when there is a shortage of water for society at large, or when the supply of water is smaller than the demand due to a weather-related disruption (Mishra and Singh, 2010).

Ecosystem: A functional unit consisting of living organisms, their non-living environment, and the interactions within and between them. The components included in a given ecosystem and its spatial boundaries depend on the purpose for which the ecosystem is defined. In some cases, ecosystems are relatively sharply defined, while in others they are diffuse. Ecosystem boundaries can change over time. Ecosystems are nested within other ecosystems, and their scale can range from very small to the entire biosphere. In the current era, most ecosystems either contain human societies or are influenced by the effects of human activities in their environment (IPCC, 2018)

Ecosystem Services: The benefits that people obtain from ecosystems. These include: a) provisioning services such as supply of nutritious food and water; b) regulating services such as climate change mitigation, flood management and disease control; c) cultural services such as spiritual, recreational, and cultural benefits; and d) supporting services, such as nutrient cycling, that maintain the conditions for life on Earth (adapted from Millennium Ecosystem Assessment, 2005).

Impacts: Effects on natural and human systems. In the IPCC WGII AR5 Report, the term impacts is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes. The impacts of climate change on geophysical systems, including floods, droughts, and sea level rise, are a subset of impacts called physical impacts.(IPCC 2019)

Land Degradation means reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as:

- soil erosion caused by wind and/or water;
- deterioration of the physical, chemical and biological or economic properties of soil; and
- long-term loss of natural vegetation. (UNCCD 1994)

Maladaptive Actions (Maladaptation): Actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas (GHG) emissions, increased vulnerability to climate change, or diminished welfare, now or in the future. Maladaptation is usually an unintended consequence. (IPCC 2019)

Resilience: The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions (IPCC, 2014).

Risk: The potential for adverse consequences where something of value is at stake and where the occurrence and degree of an outcome is uncertain. In the assessment of climate impact, the term “risk” is often used to refer to the potential for adverse consequences of a climate-related hazard on lives, livelihoods, health and well-being, ecosystems and species, economic as well as social and cultural assets, services, and infrastructure. Risk results from the interaction of vulnerability, its exposure over time (to the hazard), and the (climate-related) hazard and the likelihood of its occurrence. (IPCC 2014)

Systems approach: A holistic and interdisciplinary way of understanding and solving complex problems that views the world as a collection of interconnected and interdependent elements or people, and emphasises the relationships and interactions between them. (Cambridge University 2017)

Systems thinking: Systems thinking is a set of synergistic analytic skills used to improve the capability of identifying and understanding systems, predicting their behaviours, and devising modifications to them in order to produce desired effects. These skills work together as a system. (Arnold & Wade 2015)

Vulnerability: The propensity or predisposition to be adversely affected by a hazard. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and a lack of capacity to cope and adapt (IPCC, 2014)

Content

1 Introduction

1.1 Background (title tbd)

COP 19 (2013) established the Warsaw International Mechanism for Loss and Damage associated with Climate Change Impacts to address loss and damage associated with the impacts of climate change in developing countries that are particularly vulnerable to the adverse effects of climate change.[1] The Mechanism fulfills this role by undertaking, inter alia, the following functions:[2]

- Enhancing knowledge and understanding of comprehensive risk management approaches to address loss and damage associated with the adverse effects of climate change;
- Strengthening dialogue, coordination, coherence and synergies among relevant stakeholders;
- Enhancing action and support, including finance, technology and capacity-building, to address loss and damage associated with the adverse effects of climate change so as to enable countries to undertake actions.[3]

The Executive Committee, which comprises 20 representatives from Parties, guides the implementation of the Mechanism through a rolling workplan across five thematic workstreams. The Committee is assisted by five thematic expert groups established under these strategic workstreams. The thematic expert groups co-create knowledge products and undertake activities jointly with the Committee to promote integrated and coherent approaches to loss and damage associated with climate change impacts.

The Expert Group on Slow Onset Events was launched in 2021. Its current Plan of Action, endorsed in 2024, contributes to implementing one of the strategic workstreams that aims to enhance cooperation and facilitation in relation to slow onset events by strengthening the understanding and enhancing the capacity to address associated loss and damage, in particular at regional and national levels.

At COP 25, Parties mandated the Executive Committee and its thematic expert groups to develop technical guides within their work in their respective thematic area, covering:[4]

- Risk assessment, including long-term risk assessment of climate change impacts;
- Approaches to averting, minimizing and addressing loss and damage associated with such risk assessment;
- Resources available for supporting such approaches;
- Monitoring systems for assessing the effectiveness of the approaches

Accordingly, the relevant activities to develop thematic technical guides are incorporated into the workplan of the Committee and plans of action of respective groups. In the areas of slow onset events, an initial series of products will focus on glacial retreat, sea level rise and desertification. The Executive Committee hopes that they provide information to assist developing countries to integrate relevant responses to loss and damage associated with these climate hazards into national planning and policymaking processes.

1.2 Scope of this document

The impacts of climate change include those associated with slow onset events. Slow onset events, as initially introduced by the Cancun Agreement (COP16),[5] refer to increasing temperatures, desertification, loss of biodiversity, land and forest degradation, glacial retreat, ocean acidification, sea level rise, and salinisation. These hazards lead to compounded and cascading impacts, which unfold gradually and, in some cases, may result in far-reaching or irreversible losses on society, culture, and the environment over an extended period that affect livelihoods in the varying contexts of particularly vulnerable developing countries. The interplay and scales of these intricate processes often add to the complexity of developing effective long-term risk management strategies for given territories or connected landscapes.

This set of technical guides aims to provide a shared understanding of how to manage the impacts and anticipate risks from slow onset events in a systemic manner through examples of projected risks and impacts, and steps that stakeholders can take to respond to these risks in a timely manner, taking into account regional particularities, traditional knowledge and local practices. The guides provide information on policy options, user-friendly tools and approaches to respond to these types of slow onset events in a manner that can be tailored to the needs of policymakers, governments, implementing agencies and other relevant stakeholders at various levels. In this context, the guides also shed light on key challenges in the specific regional context and ecosystems resulting from the focal slow onset events and showcases a wide range of examples. Presented approaches and solutions do not intend to be fully exhaustive.

This guide is structured as follows:

(a) X…. placeholder

(b) …..

(c) …..

2 Desertification and slow onset events over time

"No need to worry, we have plenty of time."

2.1 Trends of global warming and impact on lands

The Summary for Policymakers of the IPCC Report entitled "Climate Change 2023" (IPCC, 2023) states clearly that human activities, principally through emissions of greenhouse gasses, have unequivocally caused global warming, with global surface temperature reaching 1.1°C above 1850-1900 in 2011-2020. Global greenhouse gas emissions have continued to increase, with unequal historical and ongoing contributions arising from unsustainable energy use, land use and land-use change, lifestyles and patterns of consumption and production across regions, between and within countries, and among individuals (high confidence)[1](IPCC, 2023).

[1] Each finding is grounded in an evaluation of underlying evidence and agreement. A level of confidence is expressed using five qualifiers: very low, low, medium, high and very high, and typeset in italics, e.g., medium confidence. The following terms have been used to indicate the assessed likelihood of an outcome or a result: virtually certain 99–100% probability, very likely 90–100%, likely 66–100%, as likely as not 33–66%, unlikely 0–33%, very unlikely 0–10%, exceptionally unlikely 0–1%. Assessed likelihood is typeset in italics, e.g., very likely. This is consistent with AR5 and the other AR6 Reports.

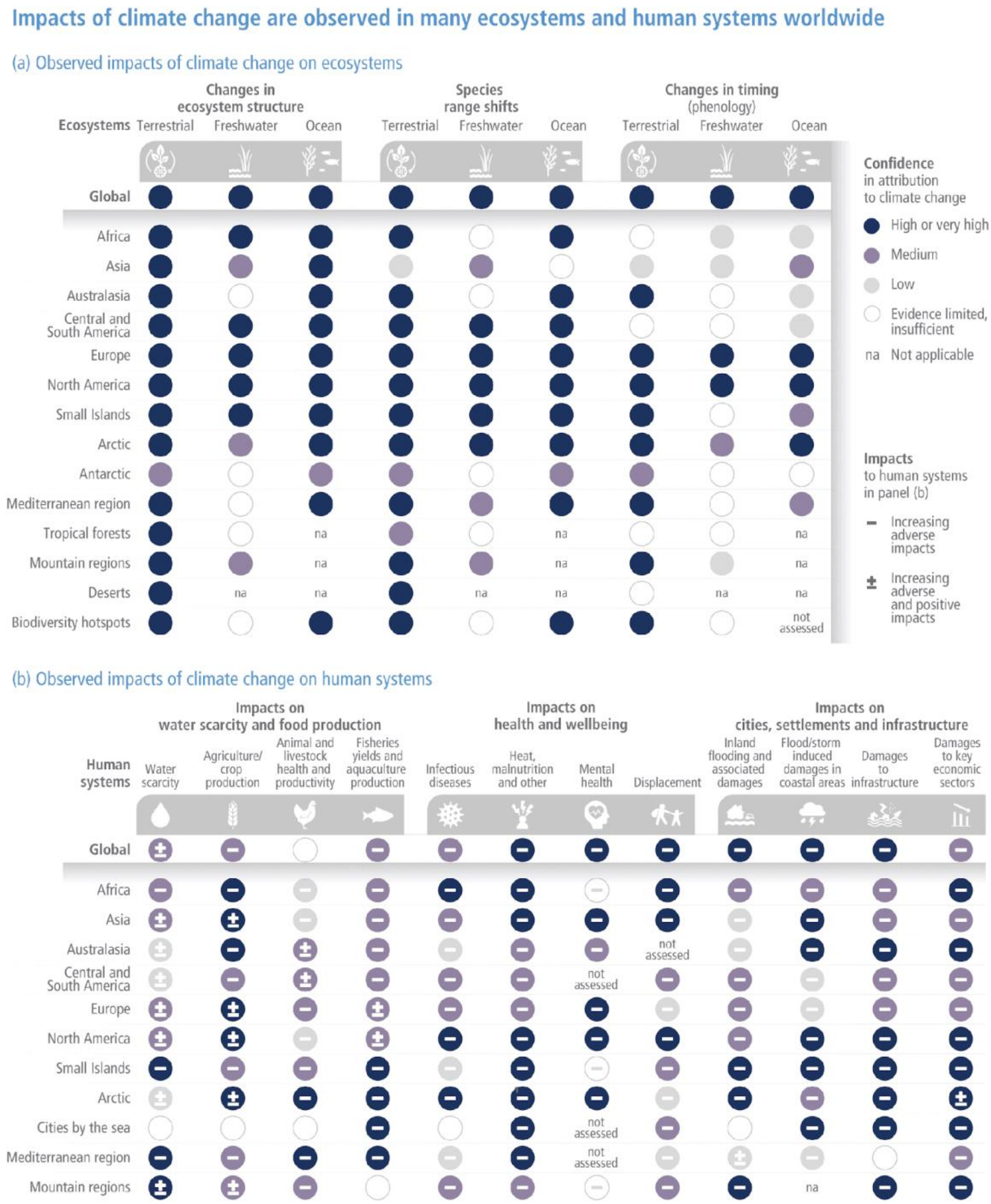


Figure 2: SPM.2 in IPCC, 2022: Summary for Policymakers

The Summary for Policymakers of the IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, entitled “Climate Change and Land” states that “**about a quarter of the Earth’s ice-free**

land area is subject to human-induced degradation (medium confidence). Soil erosion from agricultural fields is estimated to be currently 10 to 20 times (no tillage) to more than 100 times (conventional tillage) higher than the soil formation rate (medium confidence). Climate change exacerbates land degradation, particularly in low lying coastal areas, river deltas, drylands and in permafrost areas (high confidence)." (IPCC, 2019)

Desertification is a process that proceeds or recedes at unpredictable rates, its advance punctuated by extreme weather events such as droughts, heat waves and flash floods which combine to intensify and speed up the processes of desertification.

The report continues by noting that "over the period 1961–2013, the annual area of drylands in drought has increased, on average by slightly more than 1% per year, with large inter-annual variability." The IPCC AR6 report anticipates that these trends will increase as global temperatures rise.

The summary for policy makers of the Climate Change and Land report unequivocally points to the importance and urgency of policy interventions to reduce losses and damages related to the earth's agricultural lands and rangelands that are vulnerable to the impacts of climate change.

2.2 Feedback loops and the importance of understanding current and future systems

It is not easy to assess the quantitative impact of desertification distinguishing between ecological processes and human activity (XU Duanyang et al: 2011). A scenario based approach offers an opportunity and supports understanding the constellation and interaction of various driving factors in the desertification process are crucial to understand systems and take effective action.

The risk of desertification materializes when plant cover is destroyed by prolonged overgrazing, dust storms, sustained temperature rise and prolonged droughts, resulting in denuded and encrusted soil surfaces that progressively lose the capacity to absorb rain and nurture plant life, and thus to store groundwater and sustain the lives and livelihoods of pastoralists and farmers. As the processes of desertification advance, extreme rain events increasingly result in excessive soil erosion and down-stream flooding of farmland and settlements. To overcome the increasing obstacles to their success, conservation and restoration initiatives must be designed in anticipation of on-going climate change and implemented at scales that deliver ecosystem-wide positive impacts. Adaptive management will be essential to ensure necessary flexibility in response to changing biophysical and socioeconomic circumstances. Interventions should be designed to enable transformative adaptation and prevent mal-adaptive practices that enable land users to place greater stresses on ecosystems by, for example, the provision of drought relief that enables practices to be followed that place ever-greater stresses on the ecosystems.

An analysis of the causes of desertification exploring possible patterns of causes, driving forces and feedback mechanisms showed that desertification is mainly driven by a limited range of drivers (Geist and Lambin 2004). **Amongst the most prominent underlying driving forces are climate and economic factors, institutions, national policies and population growth.** This drives in turn crop expansion, overgrazing and infrastructure development and leads to regionally specific pathways of land change, with specific feedback mechanisms. Understanding these regional specific dynamics is crucial to define effective policy interventions (Geist and Lambin 2004).

3 Exploration of desertification and vulnerability

Land degradation impacts the well-being and livelihood of approximately 3.2 billion people in the world (von Keyserlingk, Thieken, and Paton, 2023) who live in dryland such as deserts and semiarid areas with lower adaptive capacities (IPCC, 2022). Most affected are populations in South Asia, circum Sahara regon and the Middle East (IPCC). In these regions, **people directly dependent on natural resources for their livelihoods and survival are the most impacted** as they often have lower capacities to adapt (Stringer et al., 2008).

There is high confidence that **climate change will exacerbate the vulnerability of dryland populations to desertification**, and that the combination of pressures coming from climate change and desertification will diminish opportunities for reducing poverty, enhancing food and nutritional security, empowering women, reducing disease burden, and improving access to water and sanitation (IPCC, 2019). In addition, land degradation gives rise to food insecurity and **makes communities more vulnerable to disasters** and increasingly intense and extreme weather events, like drought, floods, heat waves and wildfires[22].

Women and girls are particularly affected by drought and water scarcity because of their traditional role of water and fuelwood providers, negatively impacting their opportunities for education, livelihood development, migration, and exposing them to violence while leaving them out of the decision making sphere. It is critical to create space for women to ensure transformational adaptation measures (IPCC, 2022). In addition, during times of drought in Northern Kenya, it has been observed that girls are removed from school and married off early to generate an income for their family (Bradford and al., 2021).

Youth opportunities to secure decent, climate-resilient work are disproportionately impacted by the compounding effects of land degradation stressors as young people "are particularly sensitive to transformations in the economy as their activities, prospects, and ambitions are dislocated and redirected" (Bradford and al., 2021, and ILO, 2022). National policies are currently insufficiently addressing this phenomenon and there is insufficient data, especially gender disaggregated data to explore this further (Dupar and all., 2021).

Compounding crises including climate change, drought, socioeconomic factors call for a **holistic and integrated approach to adaptation** (IFRC, 2022). Effective desertification control measures require multi-stakeholder engagement (IPCC, 2022), that include all environmental stakeholders such as governments, communities and local organizations. Such engagement is needed to bridge science and local knowledge, remove policy barriers, provide finance, and drive systemic change at scale (IFRC, 2022).

The rich cultural heritage and valuable Indigenous and local knowledge present in deserts and semi-arid areas are key to enhancing local and global sustainability and land use practices**.** Effective adaptation in these regions requires supportive policies, institutions, and governance that bolster the adaptive capacities of dryland resource users, such as farmers, indigenous communities and pastoralists (IPCC, 2022).

Despite their substantial adaptive capacity rooted in Indigenous knowledge, **pastoralists have faced increasing pressure over recent decades** due to the loss of livestock corridors and pastures from competing land uses such as farming, mining, and protected areas. Governments and legal systems in many countries prioritize sedentary farming through property rights, often resulting in the erection of fences and exclusion of pastoralists. Modern states have attempted to settle pastoralists within fixed boundaries, viewing their practices as neither ecologically nor economically sustainable, promoting stall-feeding and ranching as preferable alternatives despite the contributions of such practices on increasing GHG emissions (IPCC, 2022).

The adverse effects of degradation dynamics are hard to detect immediately because they are gradual and nonlinear. Consequently, **methods for assessing future land degradation risks and developing risk reduction strategies lag** behind those for sudden natural hazards like floods or earthquakes (von Keyserlingk, Thieken, and Paton, 2023).

4 Protecting and fostering resilient livelihoods

Figure 6: Exploration of resilient livelihoods is an ongoing process (Artist: Kendra)

4.1 Understand complexities of livelihood systems

The UNCCD SPI[4] describes livelihoods as comprising the capabilities, assets and activities that lead to the well-being of a person or household and include tangible assets such as natural (timber and non-timber forest resources, water, wildlife), physical (shelter, infrastructure, equipment), and financial capital, as well as intangible human (education, skills, health) and social (institutions, relationships, trust) resources. The chosen combination of assets and activities, undertaken usually at the household level, is often referred to as the household's "livelihood strategy"[5].

Livelihood systems are complex because they are not only related to income-generation activities but other social and cultural elements. **Livelihoods depend both on ecological and socioeconomic systems and the interactions between them, which are context-specific.** Also, its complexity is related to the diversity of livelihood strategies (agriculture, pastoralism, forestry), as well as its objectives (food production, water access, incomes, fuel, health). Livelihoods are dynamic and people alter their livelihood activities and strategies depending on the internal and external stressors to which they are responding (O'Brien et al. 2004)[6]. Different groups use land in different ways within their overall livelihood portfolios[7].

Agriculture is one of the main livelihood strategies, particularly for rural communities. Family farms produce 80% of the world's food in value terms and provide livelihood opportunities for approximately two billion people, conserving more biodiversity and yielding more food per hectare than larger farms[8]. Food systems are complex and involve diverse stakeholders with different needs and aspirations; these include governments and multinational corporations, processors, traders, retailers, large- and small-scale farmers, indigenous peoples and local communities, women, and youth[9].

The livelihoods and food security of over a billion people are directly dependent upon livestock; the commerce and trade of livestock products contribute 40-50 % of the total global agricultural output and animal products provide one-third of humanity's protein intake[10], noting that men consume more meat than women across the world (Hopwood and al., 2024). **50% of the world's livestock are in the drylands**[11]. There are different types of livestock production systems, from traditional pastoral systems to commercial farms and landless production systems. Up to 500 million pastoralists herd their animals across rangelands, which are highly diverse, grass- and shrub-dominated landscapes that cover one-third of the Earth's land surface[12].

The natural resource base is also relevant for livelihoods. According to FAO (2015), in 2010, forests covered about 31 percent of the world's total land area and provided livelihoods for more than 1 billion people[13]. Studies focusing on forest resources have shown that approximately one quarter of the total rural household income in developing countries stems from forests, with forest-based income shares being tentatively higher for low-income households (Vedeld et al. 2007; Angelsen et al. 2014)[14].

Water is key for sustainable livelihoods as it is essential for agriculture, nutrition and health. **Worldwide, the agricultural sector accounts for two-thirds of global water withdrawals**[15]. Surface water affects our capacity to grow crops and raise animals, underpins industrial processes, influences the movement of diseases and toxins, generates energy, can cause loss of life and damage to property and infrastructure and also has immense spiritual recreational and cultural value in our lives[16].

Social elements are also crucial for livelihoods systems. Institution, for example, can determine if the household has access to natural assets such as land and water. More resilient livelihood trajectories can be achieved if the important role of formal and informal institutions is recognized[17]. **Socially structured gender-specific roles and responsibilities, daily activities, access and control over resources, decision-making and opportunities lead men and women to interact differently with natural resources and landscapes**[18]; consequently, gender relations within a socioecological system also profoundly influence human livelihoods.

4.2 Address current, and future impact

Just as livelihood systems are complex, so is understanding the impacts of climate change, land degradation and desertification on them. **Despite improved knowledge of the processes and effects of land degradation, on the one hand, and climate change on the other, there is still poor understanding of the complex interactions between the two and their impacts on human well-being**[19]. Nevertheless, there is evidence of the current and predicted future impact of desertification in livelihoods.

According to the IPCC[20], dryland populations are highly vulnerable to desertification and climate change because their livelihoods are predominantly dependent on agriculture. The IPCC identifies desertification as a process that can lead to reductions in crop yields and the resilience of agricultural and pastoral livelihoods and state that there is high confidence that desertification processes such as soil erosion, secondary salinisation, and overgrazing have negatively impacted provisioning ecosystem services in drylands, particularly food and fodder production.

The land degradation assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) (2018) concludes that it is well-established that **land degradation is leading to increasing poverty and worsening inequality by negatively affecting the agricultural sector and by reducing access to environmental incomes upon which low income populations are relatively more reliant**; it also highlights that land degradation has diverse and wide-reaching impacts on quality of life, causing declines in economic opportunity, food security, physical and mental health, water security, safety from conflict, and personal and cultural identity[21].

In agricultural systems, according to the IPCC[23], there is robust evidence pointing to negative impacts of climate change on crop yields in dryland areas and also robust evidence and high agreement on the **losses in agricultural productivity and incomes due to desertification**: yield decreases of up to 40–60% in dryland areas were caused by severe and extensive droughts, affecting food production. **Agricultural yields could fall by up to 50% in some African countries if production practices are not changed**[24].

On pastoralism, the IPCC[25] states that desertification coupled with climate change is negatively affecting livestock feed and grazing species, changing the composition in favour of species with low forage quality, ultimately reducing livestock productivity and increasing livestock disease prevalence.

IPCC[26] states that combined impacts of desertification and climate change on socio-economic development in drylands are complex and difficult to isolate from the effects of other socio-economic, institutional and political factors.

4.3 Livelihoods and compound and cascading risk

Climate change can accelerate or intensify land degradation, increasing current risks to human livelihoods. Hotter temperatures, along with longer, more intense droughts, wildfires, and extreme rainfall events, weaken ecological integrity and resilience in both managed and natural land systems. Many forests and grasslands around the world are now more susceptible to pest and disease outbreaks; land use change leads to greater disease transmission from animals to humans. Higher average temperatures and changes in rainfall patterns have already reduced crop yields and soil moisture. This, in turn, increases demand for groundwater extraction and irrigation, which can result in over-exploitation of these resources, further propelling desertification in the dryland regions.

Sand and dust storms have increased dramatically in recent years and are aggravated by climate change, drought, and desertification; they damage crops, kill livestock, and strip topsoil, harming food production and local livelihoods[27].

In the context of disaster risk management, desertification and land degradation have not been adequately addressed as hazards, as their effects are not immediately noticed, unlike sudden-onset events. The adverse impacts of degradation can be intermingled with the effects of extreme hydrometeorological events, which have often been perceived as the imminent threat in the past, particularly droughts[28].

There is a direct relation between desertification and drought as there is a land-drought nexus. There are strong links between land use, water use, and drought; land and drought management are fundamentally connected through the use of water via precipitation and, in some climates and systems, irrigation[29]. If droughts increase in frequency, intensity and/or duration they may overwhelm the vegetation's ability to recover ecosystem resilience, causing degradation[30]. **Land degradation may also amplify water scarcity and increase vulnerability to droughts**[31].

Drought impacts cascade across the full spectrum of economic sectors and social and environmental systems[32]. In the short term, droughts affect livelihoods systems as these systems all depend on water to different degrees. Losses to agricultural production and to all of the associated businesses – selling seeds, fertilizer, pesticides and equipment, and processing crops and livestock — are one of the biggest sources of economic loss from drought[33]. Negative drought impacts on rural crop production affect not only rural populations and livelihoods, but they can rapidly spread throughout local, regional, and global food systems and labour markets, increasing food scarcity and driving up food prices [34].

Decreased water availability caused by drought affects not only crops and livestock but also reduces access to water for domestic consumption, energy generation and transportation, which also impacts in livelihoods. Drought affects river transportation, which in turn affects agriculture and other industries that rely on this less-expensive mode of bulk transport[35].

Under certain conditions, droughts intensified by climate change can overwhelm the resilience of ecosystems and lead to major shifts in ecosystems or even their collapse[36]. Drought can cause permanent ecosystem regime change, leading to desertification and reduced provision of ecosystem services[37]. This scenario could lead to the permanent loss of habitat of wildlife that contributes to some rural livelihoods systems.

Water scarcity in drylands contributes to changes in desertification and hazards such as dust storms, increasing risks of economic loss, declines in livelihoods of communities and negative health effects[38]. Sand and dust storms (SDS) are directly linked to drought and the impacts of droughts[39] including desertification. Through reducing vegetation cover and drying the surface conditions, desertification can increase the frequency of SDS[40]. SDS impacts in livelihoods include lost or reduced income due to SDS damage to crops or reduced work opportunities, reduced food security due to these and other impacts, SDS-related health cost burdens on individuals and families and other impacts that may be noted at the individual or household levels, but not well captured elsewhere[41].

Other processes besides drought that lead to land degradation and desertification have a negative impact on livelihoods. Soil erosion increases risks of economic loss and results in declines in livelihoods due to reduced land productivity; soil erosion not only increases crop loss but has been shown to have reduced household food supply, with older farmers most vulnerable to losses from erosion.

Slow-onset changes, especially those provoking crop failures and heat stress, could affect household or individual migration decisions[45]. Livelihood-related migration can accelerate in the short-to-medium term when weather-dependent livelihood systems deteriorate in relation to changes in precipitation, changes in ecosystems, and land degradation and desertification[46]

Unabated future climate change will result in continued changes to processes involved in desertification, land degradation and food security, including: water scarcity in drylands; soil erosion; coastal degradation; vegetation loss; fire; permafrost thaw; and access, stability, utilisation and physical availability of food; and these changes will increase risks to food systems, the health of humans and ecosystems, livelihoods, the value of land, infrastructure and communities[47].

4.4 Maladaptation and short-term incentives, undermining longer term resilience

While most land-based adaptation options provide co-benefits for climate mitigation and other land challenges, in some contexts adaptation measures can have adverse side effects, thus implying a risk to socio-ecological systems.[48]

Current knowledge about the limits of adaptation strategies to address the combined effects of climate change and desertification is insufficient. However, the potential for residual risks and maladaptive outcomes is high. Some activities favouring agricultural intensification in dryland areas will be maladaptive due to their negative impacts on the environment. Agricultural expansion to meet food demands may be achieved through deforestation and consequent diminution of carbon sinks (Godfray and Garnett 2014; Stringer et al. 2012). Agricultural insurance programmes encouraging higher agricultural productivity and measures for agricultural intensification can result in detrimental environmental outcomes in some settings (Guodaar et al. 2019; Müller et al. 2017) (Table 6.12). Development and adoption of more drought-tolerant crop varieties is considered as a viable strategy for adaptation to shortening rainy seasons, but this can also lead to a loss of local varieties (Al Hamndou and Requier-Desjardins). Livelihood diversification to collecting and selling firewood and charcoal production can exacerbate deforestation (Antwi-Agyei et al. 2018). **Avoiding maladaptive outcomes can often contribute both to reducing the risks from climate change and combating desertification** (Antwi-Agyei et al. 2018). Avoiding, reducing and reversing desertification would enhance soil fertility, increase carbon storage in soils and biomass, thus reducing carbon emissions from soils to the atmosphere. In specific locations, there may be barriers for some of these activities. For example, afforestation and reforestation programmes can contribute to reducing sand storms and increasing carbon sinks in dryland regions (Chu et al. 2019). However, implementing agroforestry measures in arid locations can be constrained by lack of water (Apuri et al. 2018), leading to a trade-off between soil carbon sequestration and other water uses (Cao et al. 2018). Thus, even when solutions are available, social, economic and institutional constraints could post barriers to their implementation[49]

It is thus clear that despite the availability of numerous options that contribute to combating desertification, climate change adaptation and mitigation, there is a likelihood that some of these options will result in maladaptive actions.[50]

Restoring forests and planting trees has become a popular strategy driving global efforts and attracting much-needed funding for land restoration. However, not all land nor all species are suitable for this type of restoration. Grasslands and savannas are productive, biodiverse ecosystems that support the livelihoods of millions of people and sequester vast amounts of carbon in soils. They match forests both in their global extent and in the importance of their protection and restoration. Equally important are wetlands, which are in long-term decline, averaging losses at three times the rate of global forest loss in recent decades. Sustaining their capacity to absorb and store carbon is seen as key to a climate-resilient future. (Global Land Outlook, 2nd edition, 2022).

During the past 100 years, agricultural intensification has been driven by improved technologies and farming practices, including the use of organic and chemical fertilisers, herbicides and insecticides, development of high-yield crop varieties, improvements in land management and mechanisation and adoption of irrigation. While all of this has led to increased food production, the other side of the coin is that these advances and practices have also led to far higher rates of extraction and consumption of limited natural resources, such as water, forests and nutrients, which in many areas of the globe has led to land degradation. In addition, paradoxically, successful intensification can create economic incentives to bring additional land under cultivation, further increasing pressure on natural resources, especially for land. Although available land is likely to be less suitable than previously developed areas, it will be the "next best" option for developers, which in turn will lead to increased land degradation. Attempts to close yield gaps must be tailored to meet local conditions. Many areas with significant yield gaps are dominated by smallholder-based agriculture. These areas, in particular, offer both significant opportunities and also realistic pathways to enhance soil organic carbon, reduce local poverty and improve human well-being by adopting approaches such as agroecology. However, inappropriate agricultural intensification will result in adverse effects on natural ecosystems, which will impinge on the delivery of ecosystem goods and services critical to the sustainability of rural livelihoods[51].

4.5 Limits to adaptation and livelihood systems in the long term

As already noted, knowledge about the limits to adaptation to the combined effects of climate change and desertification is insufficient. Likewise, empirical evidence about the limits to adaptation in dryland areas is limited. Because the potential for residual risks and maladaptive outcomes is high, a critical systems approach is essential to assess and respond to the emerging evidence of the impacts and outcomes of adaptive strategies adopted by land users and managers in the global drylands that are threatened by desertification. Potential limits to adaptation include losses of land productivity due to irreversible forms of desertification. Sustainable Land Management (SLM) measures may fail to fully compensate for yield losses due to climate change impacts. Residual risks also arise from foregone reductions in ecosystem services even when the application of SLM measures may result in land regaining initial productivity. Some activities favouring agricultural intensification in dryland areas can become maladaptive due to their negative impacts on the environment (medium confidence) Even when solutions are available, social, economic and institutional constraints could pose barriers to their implementation (medium confidence).

Adaptation limits vary from place to place and are difficult to generalise (Barnett et al. 2015; Dow et al. 2013; Klein et al. 2015). Currently, there is a lack of knowledge on adaptation limits and potential maladaptation to combined effects of climate change and desertification. Moreover, although in many cases SLM measures can help reduce and reverse desertification, there would still be short-term losses in land productivity. Irreversible forms of land degradation (for example, loss of topsoil, severe gully erosion) can lead to the complete loss of land productivity. Even when solutions are available, their costs could be prohibitive, demonstrating the limits to adaptation (Dixon et al. 2013). If warming in dryland areas surpasses human thermal physiological thresholds (Klein et al. 2015; Waha et al. 2013), adaptation could eventually fail (Kamali et al. 2018). Catastrophic shifts in ecosystem functions and services (for example coastal erosion (Chen et al. 2015; Schneider and Kefi 2016) and economic factors can also result in adaptation failure (Evans et al. 2015).[52]

In managing land degradation, it is important to assess the resilience of the existing system, and the proposed management interventions. If the existing system is in an undesirable state or considered non-viable under expected climate trends, it may be desirable to promote adaptation or even transformation to a different system that is more resilient to future changes. For example, in an irrigation district where water shortages are predicted, measures could be implemented to improve water use efficiency, for example, by establishing drip irrigation systems for water delivery, although transformation to pastoralism or mixed dryland cropping/livestock production may be more sustainable in the longer term, at least for part of the area. Application of SLM practices, especially those focused on ecological functions (e.g., agroecology, ecosystem-based approaches, regenerative agriculture, organic farming), can be effective in building resilience of agro-ecosystems (Henry et al. 2018). Similarly, the resilience of managed forests can be enhanced by SFM that protects or enhances biodiversity, including assisted migration of tree species within their current range limit (Winder et al. 2011; Pedlar et al. 2012) or increasing species diversity in plantation forests (Felton et al. 2010; Liu et al. 2018a). The essential features of a resilience approach to management of land degradation under climate change are described by O'Connell et al. (2016) and Simonsen et al. (2014) [53].

In the context of land degradation, potential limits to adaptation exist if land degradation becomes so severe and irreversible that livelihoods cannot be maintained, and if migration is either not acceptable or not possible. Examples are coastal erosion where land disappears (Gharbaoui and Blocher 2016; Luetz 2018), collapsing livelihoods due to thawing of permafrost (Landauer and Juhola 2019), and extreme forms of soil erosion, (e.g., landslides (Van der Geest and Schindler 2016) and gully erosion leading to badlands (Poesen et al. 2003)) [54].

5 Maintaining Healthy and Resilient Ecosystems

I just don't know what we can do about climate change.

Kendra Allenby / CartoonCollections.com

Everywhere on the planet humans depend on ecosystems to provide the services on which society depends, ranging from clean, oxygen-rich air to food and fibre from plants and animals, from potable water to construction material for shelter. **Dryland ecosystems are more vulnerable than many others to the perturbations of climate change and extractive human activities, and the expansion of desertified areas is an on-going trend** (ref GLO).

Dryland soils and the vegetation that they host have evolved under climates that are subject to periodic extremes of temperature, aridity, humidity and air movement. Permeable soil surfaces are essential to enable the recharge of the ground water resources upon which ecosystems and human inhabitants of the drylands depend for their survival (Tanner & Hughes 2015).

Soils have a close relationship with climate, as they have evolved the ability over millions of years to sequester atmospheric carbon in the form of soil organic carbon (SOC). Simultaneously, and especially since mankind has been clearing vegetation and ploughing the soil for food production, soils have become a net emitter of carbon, contributing to the relatively mild climate that has engendered the development of civilisations in many parts of the world. The current crisis of excessive global temperature is directly linked to a crisis of excessive denudation of soils and loss of soil organic carbon to the atmosphere (Lal 2003).

In the context of desertification, the loss of vegetative cover of the soil is directly linked not only to increased levels of atmospheric carbon (Crtichley et al 2023), but is also to loss of livestock-based livelihoods and diminishing availability of groundwater. Effective adaptation to the impacts of climate change that results in increases in vegetative cover also contribute to global efforts to mitigate climate change. Not only do plants store carbon within their structures, but soils that are protected by vegetation are more able to store carbon. Vegetation also regulates soil temperatures which in turn affect atmospheric temperatures. Denuded landscape heat up and cool down significantly faster that those clothed in vegetation, and are vulnerable to the effects of high velocity winds that can transport surface dust and soil particles, which in turn may bury seedlings and sand-blast the living part of plants and cause further denudation (Stefanski, R. & Sivakumar, M.V.K. 2009.).

Groundwater resources in the global drylands are a vital resource for the livelihoods of pastoralists and agriculturalists. In the modern era mechanical extraction of groundwater has enabled the intensification of grazing on rangelands that were previously only used when seasonal rains provided surface water resources for livestock. Whereas this has vastly increased the productivity of pastoral systems, it has also created opportunities for land users to overgraze rangelands to the extent that vegetation is trampled to death and plants are unable to effectively reproduce because their flowers and seeds are grazed excessively. In many dryland areas, past climatic epochs have created vast underground reservoirs of fossil water (Lloyd 1990). These resources have in many instances been overexploited to feed the demand for irrigated crops, leading to their exhaustion, which has impacted negatively on others who had previously used these resources for domestic purposes and to water livestock.

Rivers and other surface water resources in the drylands have long been used to irrigate crops. In the modern era technologies such as enhanced irrigation techniques and the construction of reservoirs have enabled vast expansions of irrigated areas in the global drylands. Despite the benefits to mankind these advances have come at huge environmental cost. In Central Asia, over-exploitation of the Syr Darya and the Amu Darya Rivers has led to the drying of the Aral Sea, once the fourth-largest freshwater lake in the world (ref). Over-irrigation of alluvial lands in countries such as Iraq is also associated with salination as salts are enabled to rise from substrate into topsoil.

The plants that have evolved in the global drylands are uniquely adapted to the climate and soils that occur in these locations. In past ages, influenced by climatic cycles including ice ages and greenhouse eras, the native vegetation of the drylands has evolved resilient adaptive strategies that make it uniquely suited to these environments. Conserving native biodiversity is thus crucial for future adaptation as this resource is already uniquely adapted to climatic extremes. **As ecosystems transform due to changing climate it will be crucial for the future livelihoods and well-being of dryland communities to deepen their appreciation of native plants and to their current and potential future contributions to livelihood systems**.

6 Systemic long-term perspectives

No thanks, we're going to create some alternative options over here. Want to join?

Kendra Allenby / CartoonCollections.com

The complex and interlinked ecological, economic, social and governance systems upon which humanity relies are increasingly subject to turbulence and uncertainty as humanity strains against the bounds of the planet's capacity to sustain the increasing populations and their demands for energy, shelter, food and consumer goods. At the same time **humanity is increasingly aware of the need to strive for the ways and means to meet these needs in ways that are more equitable, sustainable and resilient for both current and future generations**. Current and predicted future trends clearly indicate accelerating increases in contestation, interconnection and complexity in ways that will likewise increase the number and frequency of unpredictable disruptions as a result of the concatenation of causes such as climate change, inequality and weakening social cohesion, stresses on global financial systems and health challenges. All of these factors feed into increasing geopolitical competition and tension, exponentially increasing the numbers of displaced people who have been deprived of the means to create sustainable livelihoods (Bendell 2018).

In these circumstances older and more rigid linear approaches to anticipating and addressing the causes and results of this turbulence and uncertainty, which can be described as "systematic" are increasingly shown not only to be ineffective, but indeed to even contribute to the creation of greater and unanticipated challenges (Ison 2010). These systematic approaches are applied in the design and implementation of **most projects, and are typically situated in what Winter and Checkland (2003) describe as the 'hard systems paradigm',** which imagines the future outcomes of investments and actions to achieve pre-defined goals and targets. This approach is of great value in designing "hard systems" such as photo-voltaic systems. However, natural and human systems, which can be characterised as self-organising complex adaptive systems function in very different ways and require unique institutional responses (Woodhill and Millican 2023).

Decision-makers at all levels must be informed by a holistic understanding of the 'big picture' and equipped to respond with a systemic understanding of the underlying causes and interconnections that underpin the systems. This in turn points to why it is essential that these decision-makers should be competent systems thinkers who are able to draw from a wide range of expertise and skills, both conceptual and practical (Ison 2010). This combination of capacities will enable them to guide and influence the changes to local and global systems that will be needed if humanity is to flourish and not to decline during the Anthropocene. Systems change is a complex and delicate process that takes place in the context of the power dynamics, incentives and disincentives of the wider political economy. Systems thinking provides a powerful set of tools and concepts to gain greater understanding of these dynamics. As such, they enable decision makers to design and adapt interventions and their associated investments in ways that are better informed about the social and political complexity and unpredictability of human societies. Well informed interventions that are situated within a dynamic of on-going analysis of new information and learning about the larger systems within which they function will be more likely to succeed.

If long-term losses are to be minimised and some livelihoods are to be retained, adapted or re-designed in areas affected by desertification, a systems approach will be vital for managing ecosystems in the context of increasing frequency and severity of droughts. **A systems approach is rooted in the understanding that any whole entity or system is different from the sum of its parts**. Bawden (1994) notes that "the process of interconnection of parts results in the emergence of special properties that are characteristic of the whole, yet were not apparent in any of the parts" of the system. Changes in one part of any complex system, whether this be a biological system or a system created by humans such as an economy or a farming system, will result in relatively unpredictable changes in other parts of the system. Linear cause-effect models are inadequate to anticipate or describe complex feedback loops and compounding, incremental changes.

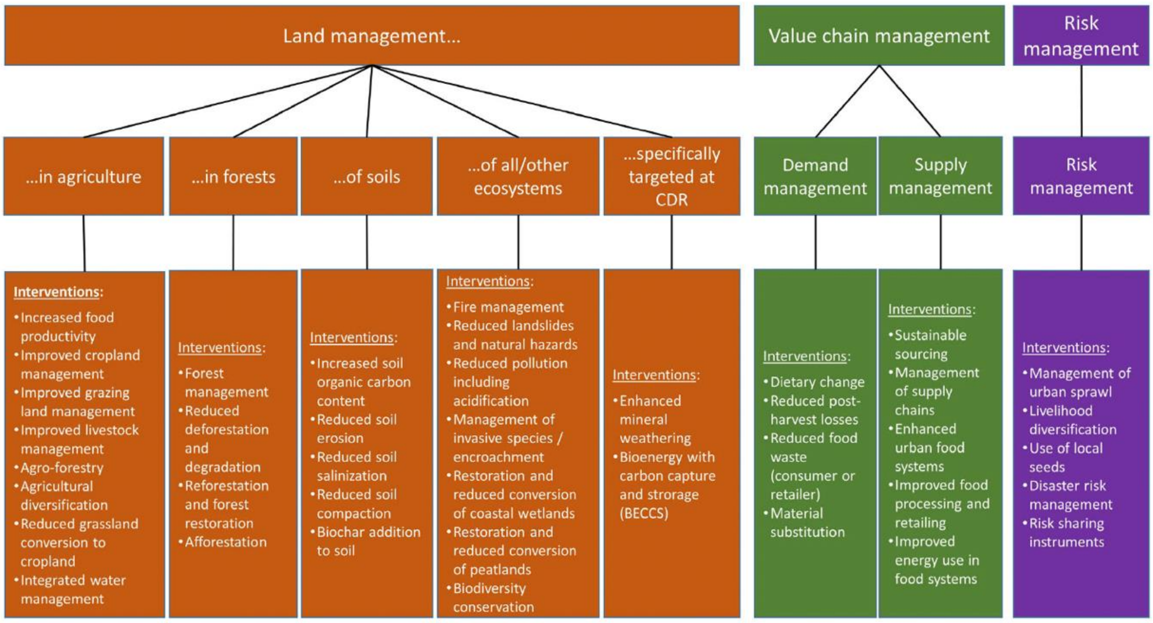
A systemic approach will require access to a large range of biophysical, social and economic data and information coupled with a real-time ability to analyse and respond to the emerging realities. Elements that are critical to analyse desertification in a comprehensive manner. Governments are typically not designed for the implied systems intelligence and nimbleness of action that is required. The IPCC report notes that although intersectoral coordination is key, in many countries, roles related to drought reside in different Ministries (Environment, Agriculture, and others) and in some cases, there is not clarity on which organisation is the provider of the official information on drought, and the data generated by different entities is not conciliated. **It is essential that the responses to the emerging realities of drought impacts should not only mitigate the severity of the impacts, but should also contribute to increasing resilience and diminished dependency amongst affected populations.** Ill-considered and inappropriate responses can have diametrically opposite impacts. Improved intersectoral design, coordination and adaptive management of responses within the context of a broader systems understanding is thus crucial.

7 Possible adaptation options

Kendra Allenby / CartoonStock.com

As illustrated in the infographic below, Smith et al (2019) distinguish three different types of adaptative practices: The first one is focusing on land management in agriculture, forests, soils and ecosystems. The second one suggests to address value chain management (management of demand and supply) and finally the last one focuses on risk management approaches to support short term interventions as well as long term planning and implementation. We refer to some concrete examples for these approaches. It is important to note that these practices often overlap and will take place in the same system, but at different temporal scales (from short term response to long term management approaches).

Figure 4: Broad categorisation of practices (Smith et al, 2019)



7.1 Increase resilience of current livelihood strategies

Complexity of the livelihoods systems in areas affected by land degradation and desertification demand of different adaptation responses, ones that would be transformative. Adaptation options may be planned, such as those implemented at regional, national or municipal level (top-down approaches), or autonomous, such as many technological decisions taken by farmers and local inhabitants[1].

Sustainable land management (SLM) technologies and practices can increase resilience of current livelihood strategies. SLM practices in drylands increase agricultural productivity and contribute to climate change adaptation with mitigation co-benefits[2]. The IPBES (2018) assessment provides science-based evidence that reducing new degradation via SLM or reversing land degradation with rehabilitation and restoration measures will positively contribute to the wellbeing and livelihoods of people and environmental conditions[3]. Some examples of SLM practices highlighted in the IPCC "Climate Change and Land" report, the UNCCD and the UNCCD SPI are shared below.

7.2 Integrated crop–soil-water management

Integrated land and water management practices have proven effective in reducing risk and improving drought resilience by increasing soil productivity, and make farming less risk-prone. [4].

The adoption of intercropping (inter –and intra-row planting of companion crops) and relay cropping (temporally differentiated planting of companion crops) maintains soil cover over a larger fraction of the year, leading to an increase in production, soil carbon and nitrogen, species diversity above and below the soil surface and a decrease in pest abundance[5].

Activities, such as those associated with conservation agriculture (minimising tillage, crop rotation, maintaining organic cover and planting a diversity of species), reduce erosion, improve water use efficiency and primary production, increase inflow of organic material and enhance SOC over time, contributing to climate change mitigation and adaptation[6].

Integrated soil fertility management seeks to optimize soil nutrients and water for crop growth, which is achieved by combining the application of chemical and organic soil additives, such as livestock manure, compost, green manure, bio-humus and biochar, building on indigenous and introduced practices as Terra Preta raised garden beds (Haiti) (https://qcat.wocat.net/af/wocat/technologies/view/technologies_935/), and keyhole gardens (Lesotho), chinampas (using interweaving reeds in water bodies to create plots for crop production) and milpas (shifting cultivation) in Mexico [7].

Better water management, coupled with improved soil and crop management, can increase agricultural productivity in rainfed areas with currently low yields by more than double and some technologies are use of sustainable irrigation systems, water harvesting and drainage[8].

There is robust evidence and high agreement that the implementation of rainwater harvesting systems leads to an increase in agricultural production in drylands[9]. Resilience against droughts in rainfed crop production could also be enhanced by supplemental irrigation using various rainwater harvesting techniques and there are numerous examples of rainwater harvesting techniques adapted to local conditions across the world, such as Zai pits (Burkina Faso), Tassa (Niger), Ndiva (Tanzania), sub-surface water harvesting, kyariz systems (Turkmenistan), rock catchment, pond sand filters and others[10].

7.3 Grazing land management

Improved grazing land management can improve the resilience of grazing lands to future climate change, help reduce desertification and land degradation by optimising stocking density and reducing overgrazing, and can enhance food security through improved productivity[11]. Rivera-Ferre et al. (2016) list as adaptation strategies with high potential for grazing systems, mixed crop–livestock systems or both: crop–livestock integration in general; soil management, including composting; enclosure and corralling of animals; improved storage of feed[12].

Exclosures (i.e., areas protected from grazing) and rotational grazing, or even continuous grazing with low stocking rates, are proven methods for restoring grassland health and productivity (e.g., improved soil structure, water retention/infiltration), even more so when they are managed to enhance connectivity within the wider landscape[13].

Rotational grazing approaches help reduce rangeland degradation by modifying and spreading out grazing pressure, but when confronted with droughts, local rotational grazing is often insufficient, and other measures need to be used, such as long distance movement of livestock to areas not affected or less affected by drought, in situ drought survival stall feeding of livestock, establishment of fodder banks and herd management practices which involve the choice of species composition that maximizes the pastoralist's capacity to overcome drought impacts without depleting their livestock asset base[14].

As is the case with croplands, carbon storage in grazing lands can be improved by a variety of measures that promote productivity, such as alleviating nutrient deficiencies with fertilizers or organic amendments and manure separation to better distribute organic matter[15].

All of these approaches must be assessed within the national and local contexts within which the grazing systems are managed, and an evolving combination of incentives (including provision of extension and educational services, provision of material inputs and improved pricing and market access) must be deployed to promote beneficial approaches. The adoption and use of such incentives should be monitored with pastoralists to ensure that they do not result in maladaptive responses. Simultaneously market distortions that encourage environmentally destructive practices must be addressed and regulations adapted to limit excessive exploitation of natural resources at levels that are only sustainable for relatively short periods during times of above-normal precipitation.

7.4 Sustainable forest management

Sustainable forest management can contribute to increasing the resilience of livelihood systems that are highly dependent on natural forests and woodlands. Sustainable forest management measures that appropriately manage forest fires and their spread serve as measures for increasing drought resilience in forested areas themselves; these measures include reducing surface fuels, decreasing the potential for human-caused forest fires, prescribed burning, and others[16]. Other examples of sustainable forest management measures that enhance the provision of goods and services for local livelihoods are silvicultural practices, assisted natural regeneration and restoration of degraded forest patches.

Farmer Managed Natural Regeneration (FMNR) is a sustainable forest management agroforestry practice that has been extensively applied in the Sahel region of Sub-Saharan Africa. It consists of protecting and managing the natural regrowth (shoots) produced by tree and shrub stumps in the field. It refers to a method of spontaneous reproduction of plants either by seed or vegetatively from stump sprouts. Farmers deliberately select woody plants during crop clearing and field preparation for a variety of purposes. Abasse et al (2023) note that farmers in south-central Niger cumulatively added at least 200 million trees and shrubs to their production systems, sequestering significant amounts of carbon. Reij and Winterbottom (2015) estimate that these agroforestry parklands in Niger sequester between 1.6 and 10 t/ha in their biomass. Cumulatively, these practices are estimated to have contributed 30 million tons of sequestered carbon (Reij and Garrity, 2016). Saidou (2021) has shown that landscapes revegetated by sustainable land management actions have a mitigating effect on climate change and variability.

7.5 Locally led adaptation, local knowledge and livelihoods: averting and minimising loss and damage

The resilience of local livelihoods depends on the capacities of communities to adapt, diversify and innovate with technologies and approaches, combining local and traditional knowledge with new learnings. Collective action, indigenous and local knowledge (ILK) are still crucial to the ability of households to respond to the combined challenge of climate change and desertification[1].

Increasingly it is recognised that it is important that decision-makers should understand how ILK informs land users' responses to degradation. Scientists and farmers have been able to recognise each others' expertise in processes of knowledge co-production and co-innovation which creates rich opportunities to introduce, implement, adapt and promote the use of locally appropriate responses[2]. The use of IKL enhances the success of SLM and its ability to address desertification and there are abundant examples of how ILK has enabled livelihood systems in drylands to be maintained despite environmental constraints[3].

BOX

Some of these examples are:

- Across the Arabian Peninsula and North Africa, informal community by-laws were successfully used for regulating grazing, collection and cutting of herbs and wood, and which limited rangeland degradation.
- Pastoralist communities in Morocco developed the Agdal system of seasonally alternating use of rangelands to limit overgrazing as well as to manage forests in the Moroccan High Atlas Mountains (Auclair et al 2011).
- Pastoralists in Mongolia developed indigenous classifications of pasture resources which facilitated ecologically optimal grazing practices (Fernandez-Gimenez 2000).
- In the Philippines, traditional integrated watershed management by indigenous people sustain regulating services vital to agricultural productivity, while delivering co-benefits in the form of biodiversity and ecosystem resilience at a landscape scale (ref).
- Traditional knowledge that informs rice cultivation in the uplands of East Borneo, grounded in sophisticated shifting cultivation methods (gilir balik) has been passed on for generations (more than 200 years) in order to maintain local food production (ref)..
- Numerous traditional water harvesting techniques that are used across the global drylands to adapt to dry spells and climate change, including creating planting pits (zai, ngoro) and micro-basins, contouring hill slopes, terracing and replenishment of aquifers (amunas in the Andes) (ref)..

Policy actions promoting the adoption of SLM practices in dryland areas, based on both indigenous and local knowledge and modern science, and expanding alternative livelihood opportunities outside agriculture can contribute to climate change adaptation and mitigation, addressing desertification, with co-benefits for poverty eradication and food security[4].

Livelihood resilience will also depend on the ability of dryland agricultural households to diversify their livelihoods sources. For many small-scale producers, crop and livestock diversification is key to improving resilience and productivity while reducing environmental risks, especially in areas with declining soil health[1]. Livelihood diversification through non-farm employment increases the resilience of rural households against desertification and extreme weather events by diversifying their income and consumption, however, access to alternative opportunities is limited in the rural areas of many developing countries, especially for women and marginalised groups who lack education and social networks[2].

Farmer-led innovations can better adapt to local contexts and have higher adoption rates. Farmer-to-farmer sharing of their own innovations and mutual learning positively contribute to higher technology adoption rates and this innovative ability can be given a new dynamism by combining it with emerging external technologies, for example, emerging low-cost phone applications ('apps') that are linked to soil and water monitoring sensors can provide farmers with previously inaccessible information and guidance [3].

Alternative livelihoods also include the change of consumption patterns and dietary change. A 'contract and converge' model of transition to sustainable healthy diets would involve a reduction in over-consumption (particularly of livestock products) in over-consuming populations, with increased consumption of some food groups in populations where minimum nutritional needs are not met[4].

7.6 Approaches to increasing agency

Collective action has the potential to contribute to sustainable land management (SLM) and climate change adaptation (Adger 2003; Engdawork and Bork 2016; Eriksen and Lind 2009; Ostrom 2009; Rodima-Taylor et al. 2012). Collective action is a result of social capital. Social capital is divided into structural and cognitive forms: structural corresponding to strong networks (including outside one's immediate community); and cognitive encompassing mutual trust and cooperation within communities (van Rijn et al. 2012; Woolcock and Narayan 2000). Social capital is more important for economic growth in settings with weak formal institutions, and less so in those with strong enforcement of formal institutions (Ahlerup et al. 2009). There are cases throughout the drylands showing that community by-laws and collective action successfully limited land degradation and facilitated SLM.

7.7 Regenerative Agriculture, Agroecology

Agroecological approaches and regenerative practices stimulate greater resource use efficiency, helping to protect and restore biodiversity and ecosystem services. 39 These practices can lead to higher total farm yields and better nutritional values when compared to resource-intensive monocultures.40 When supported by the right policies and regulations, improved soil health will increase not only land productivity and biodiversity, but also the total amount of carbon sequestered. (Global Land Outlook, 2nd edition, 2022).

Agroecological and regenerative methods are particularly well-suited to small-scale food producers, who typically rely on low-tech and labor-intensive practices. Reduced dependency on external inputs (e.g., agrochemicals, heavy machinery) saves money and reduces harmful environmental impacts, such as groundwater pollution, soil compaction, or erosion. In many cases, the uptake of regenerative practices is dependent on farmers funding the start-up costs associated with revitalizing soil health. Supporting and investing in smallholders is a pro-poor approach to scaling up nature-positive food production. Almost 30% of small farms have already shifted to more sustainable practices, accounting for 9% of global agricultural land. Aligning small-scale production to local and regional demand for diverse, nutritious foods can reduce the pressure to expand farming into natural ecosystems while simultaneously revitalizing the urban-rural linkages necessary for a healthy regional economy. Secure land tenure and access to technology, credit, and markets all support the role of smallholders as agents of change and encourage the uptake of agroecological innovations. (Global Land Outlook, 2nd edition, 2022).

Many traditional and modern food production practices can enable agriculture to pivot from being the primary cause of degradation to becoming the principal catalyst for land and soil restoration, leading to transformative adaptation measures. As with all innovation that disrupts established systems, this transformation will require time and money. Sustainable food production alternatives, inspired by agroecological approaches, are affordable and effective. The transition to regenerative agriculture practices will entail variable timescales, approaches, and incentives depending on the scale and resource use intensity of food producers. (Global Land Outlook, 2nd edition, 2022).

7.8 Migration and resettlements -challenges on non-economic losses

Migration is frequently used as an strategy to avert, minimize and address losses and damages to environmental change. Migration is a form of livelihood diversification and a potential response option to desertification and increasing risk to agricultural livelihoods under climate change (Walther et al. 2002). Migration can be short-term (e.g., seasonal) or long-term, internal within a country or international.

This will be further explored in the guides on migration and non-economic losses and damages.

8 Food security

Globally, climate change is having profound negative effects on food systems, while food systems contribute to a changing climate. Food systems are also responsible for the accelerated pace of natural resource degradation at the same time that they are affected by it (HLPE 2020).

In addition to climate change, food systems face numerous other challenges, including the degradation of natural resources, conflict, population change and inequities in access to food and agricultural resources, among others.

Incorporating sustainability into the concept of food security and nutrition is vital because growing trends such as climate change and degradation of natural resources, as well as growing social and economic inequality, will undermine the capacity of ecological systems to interface with social and economic systems to support diverse and healthy food production and food system livelihoods into the future. Ecological, social and economic systems must engage effectively so as to create regenerative synergies if humanity is to enjoy the benefits of food security long into the future.

In order to advance these goals, there is an urgent need for a more effective policy framework to facilitate a fundamental transformation of food systems to better address these highly complex situations (ibid).

The High Level Panel on Food Security and Nutrition notes that policies that promote a radical transformation of food systems need to be empowering, equitable, regenerative, productive, prosperous and must boldly reshape the underlying principles from production to consumption (HLPE 2020). These include stronger measures to promote equity among food system participants by promoting agency and the right to food, especially for vulnerable and marginalized people.

In order to promote transformation of food systems, more sustainable food production practices such as agroecology that also empower producers while also addressing climate change and ecosystem degradation will be essential (ibid). Furthermore, measures to reshape food production and distribution networks, such as territorial markets, help to overcome economic and sociocultural challenges such as uneven trade, concentrated markets and persistent inequalities by supporting diverse and equitable markets that are more resilient.

In turn, environmental degradation (resulting from unsustainable diets) can exacerbate negative impacts on health, for example, from climate change and agricultural pollution associated with land clearing and highly industrialized modes of agriculture (IPES-Food, 2016).

The livelihoods of many food producers are being pushed to breaking point by climate change and environmental degradation. Nearly one billion people who derive their livelihoods primar- ily from agriculture are presently living in vulnerable environments. Modern agriculture is failing to sustain the people and resources on which it re- lies, and has come to represent an existential threat to itself (ibid).

Intact ecological systems and land management practices remain the important backbone of food security. While some adjustments in the value chain are possible measures, While the impact of desertification as a slow onset event might often be hard to quantify over time, we need to note that there are several opportunities on the demand based management that will have a strong effect on mitigation such as dietary change (high confidence), reduced post-harvest loss (high confidence) and reduced food waste (high confidence). (Smith et al, 2019).

From an adaptation perspective, land management and risk management are considered to have the most important benefit for adaptation. In particular a few practices can be highlighted:

1. Increasing food production by sustainable intensification (affecting more than 163 million people)
2. Improved cropland management, while considering both, the preparedness and management of extreme events and the management over decadal timescales.
3. Agricultural diversification of agricultural systems to achieve climatic resilience (Campbell et al., 2014; Cohn et al., 2017)
4. Reducing conversion of rangelands to crop lands to stabilise soils leading to improved resilience to extreme events. However this approach might have a negative impact for food security, as agricultural cropping land produces more food overall.
5. Integrated water management provides an important contribution to adaptation to desertification as a Slow Onset Event (SOE), especially when the resilience of crop production systems to future climate scenarios is improved. This should include improved irrigation systems and integrated water resource management for urban and rural populations.

10 Systems approaches to avert, minimize and address loss and damage

An increasingly wide range of tested and promising technical solutions are available to address the challenges posed by climate change induced desertification. However, it is crucial to situate these within the context of the interactions between the complex natural and human systems that will determine the relative success or failure of initiatives and practices intended to advance sustainability.

A strategic systems approach will enable responses to be designed that anticipate future climatic, technological, social, political and economic circumstances within the context of a timescale that must effectively address a wide temporal scale from the short term to the very long term (30-50 years).

It is evident that different regions of the globe will be affected by desertification in different ways and to different degrees. Whereas climate models and emerging trends provide indications of these effects, it is impossible to predict with any degree of certainly where, to what extent and in what ways these will manifest. Different responses will be needed and must be tailored to the local circumstances by the problem owners and implemented in ways that are responsive and adaptive.

Resource constraints will constrain the ability of actors to take certain actions and modify their practices. It will be crucial to ensure that limited resources are wisely invested into sound solutions, with an appreciation of the challenges related to scalability. What is effective at a local level may not be replicable at other levels or in other contexts. The response hierarchy adopted by the UNCCD to achieve Land Degradation neutrality (Avoid, Reduce, Reverse) should guide investment of funds and other resources at all times.

Political capital to address environmental ills is a scarce commodity that must be invested wisely and in regulating effectively in the most crucial locations and to achieve viable outcomes. Caution must be exercised to avoid investing in politically popular interventions with short-term benefits that result in long-term damage to the environment and the livelihoods that depend on it.

Much as efforts should focus on maintaining the current livelihoods of land users and their communities, in some circumstances it will be important to confront the uncomfortable prospect that losses and damagers will incur and limits to adaptation will be reached and that alternatives will have to be found by, and for affected populations. Paradigm shifts may be needed to adapt livelihood approaches in circumstances where the limits to adaptation have been be reached

11 Regional Examples

Regional Example #1

Based on the case study 2 “ZAÏ”, The practice that stopped the desert in United Nations Convention to Combat Desertification. 2019. The Global Land Outlook, West Africa Thematic Report, Bonn, Germany.

Zai technique to overcome desertification in West Africa		
Region	Scale	Focus Soil restoration and water management

Context: People, ecology, geography

Burkina Faso is a landlocked country in the West African Sahel region. The Gourga forest extends over 25 ha in semi-arid areas in the north of the country (UNCCD, 2019). The population of the country is approximately 20.1 million (2020) people. With 80% of the workforce having a livelihood related to agriculture. Food supplies are affected by rainfall declines, dust storms and heat waves affecting communities and livelihood Mining activities related to gold have also increased in recent years. It ranked 144th among 157 countries in 2020 on the human capital index, with 40.1% of its population living below the national poverty line (World Bank, 2024). Soils are largely degraded in the country, with studies indicating that 74% of the land is affected by desertification and droughts as of 2013. In the northern region and compounded with population pressure and decades of continuous rainfall decline, a sharp decline of agricultural yields has been observed (UNCCD, 2019). Burkina Faso is prone to drought, flash floods, windstorms, and disease outbreaks. (World Bank, 2024).

Challenge: What is the challenge that these processes are aiming to address?

The Zai technique is aiming to address land degradation and the impacts of the continuous rainfall decline on agricultural yields.

Action: What did people do to address the challenges?

Led by Yacouba Sawadogo, communities have promoted the Zaï in various forums. This is an traditional yet innovative agricultural practice consisting in improving soil structure by creating small depressions in the soil (from 30 to 40 cm large, and 10 to 15 cm deep), to which compost can be added and using the soil extracted to enhance the water and compost capture. Used at the beginning of the dry season, the Zaï allows for the soil to collect and retain more water in increasingly fertile soil for crops once the rainy season comes (UNCCD, 2019). Recent researches are also showing that Zai are more effective to capture carbon as well as creating agroforestry ecosystems. (Belmin, SawadogoMore and N’Dienor, 2023).

Lessons learnt and recommendations:

This method is effective and sustainable but can be time consuming. As this technique is spreading in the Shael, recent research and activities around Zai have shown that it is possible to use mechanical tools to create Zai in less time.

Regional Example #2

Based on the case study 3.2. Ngitili agrosilvipastoral systems (Tanzania) in United Nations Convention to Combat Desertification. 2019. The Global Land Outlook, East Africa Thematic Report, Bonn, Germany.

"Ngitili" a Traditional Agrosilvopastural Restorative and Systemic Tool in Tanzania		
Region	Scale	Focus
East Africa	300,000-500,000 ha had been restored across 833 villages	Agropastoralism and community-led management

Context: People, ecology, geography

The United Republic of Tanzania is the largest country in East Africa. The country's population was approximately 59.7 million people in 2020.Despite the country to lower-middle-income country status in 2020, there is a constant increase in the number of people living below the national poverty line to steadily increase due to Tanzania's rapid population growth. The economy is based on industrial, construction, and agricultural sectors. Tanzania is prone to numerous risks from extreme weather events including increased seasonal variation in rainfall and temperature, and frequent and prolonged droughts and floods (World Bank, 2024).

The Meatu district in Shinyanga is a pastoral and semi-arid region of northern Tanzania. It is composed of grassy savannah woodlands, with erratic rainfall is erratic and evapotranspiration and surface runoff. Local economic activities include cattle rearing, mining and the culture of maize, sorghum, bulrush millet, cassava, rice and chickpeas. The region became known as 'The Desert of Tanzania' following extensive land degradation occurring in between 1930s and 1960s. This was induced by increasing population, insecure tenure rights, government-organized woodland clearing to manage tsetse flies and trypanosomiasis, and resource exploitation. These challenges were compounded by changes in rainwater within a few years with less tainfalls (UNCCD, 2019).

Challenge: What is the challenge that these processes are aiming to address?

As a result of the land degradation, ecosystem goods and services were disrupted, with negative consequences on agropastoralists systems. The challenges are to

Action: What did people do to address the challenges?

The traditional agropastoral "ngitili" system has been included in the government-led initiative "Hifadhi Ardhi Shinyanga". This system aimed to keep standing vegetation throughout the rainy season, sheltering the production of fodder and grass and increasing tree stocks. It was implemented in sites ranging from 0.2 to 20 hectares as well as communal sites up to 50 ha, eventually reaching up to 500,000 ha across 833 villages (UNCCD, 2019).

Additional community-based components have been implemented such as an assembly managing the system and eventual conflicts, local guards enforcing compliance with the system, environmental village committees and village-lead regulation on the crop selection and division of the surplus (UNCCD, 2019).

Lessons learnt and recommendations:

Built on traditional knowledge: The 'ngitili" system is a traditional knowledge that has been lost for a few decade before farmer requested for the technique to be used again. As the mechanisms for establishing, monitoring, and enforcing "ngitili" were rooted in existing customary land governance traditions and derivative village by-laws, this greatly contributed to the social acceptability of the project.

Locally-led action: Communities played an important role in setting the systems and adapting them to the local needs with community members involved in the different mechanisms created increasing the community ownership and the success of the measure.

Collaboration and equity: Many decisions have been made in a cooperative manner amongst the local community to manage the commons in most cases in a fair and equitable way. Over 90% of the population in the targeted villages had access to a village, family or individual *ngitili*.

Regional Example #3

Addressing drought and poverty in Barind, Bangladesh		
Region Indian sub-continent	Scale 583,000 ha	Focus Restoring productivity in degraded agricultural areas via groundwater irrigation

Context: People, ecology, geography

Barind is a drought-affected area of 7,770 sq. km in the north western part of Bangladesh. In 2014 the total population of the region was 2,958,838 of which 82 % were rural and comprised 700,000 households. A majority of land users are small farmers with less than 1ha of land. Barind is one of the driest and hottest areas in the country. Rainfall in the area varies from about 1500 mm to 2000 mm per annum and temperature ranges from 4 to 44 degrees Celsius. The area is at a comparatively higher elevation than the adjoining floodplains, between 40m and 20 m above sea level. Cultivated land is 583,000 ha in extent.

Clearing of trees in the colonial era led to the entire area becoming drought-prone and desertified during the dry season. The now-shadeless region became hotter, and the soil less able to hold moisture. Run-off of rainwater exceeded infiltration, causing erosion of surface soil and nutrients. Wind erosion during the hot summer period was succeeded by water erosion during heavy monsoon downpours.

Prior to development of tube wells the area was predominantly single cropped, and yields were poor and subject to seasonal drought. No crops could be grown during the dry "rabi" season (November to May). The impacts of drought were severe and affected food insecurity and livelihoods.

Challenge: What is the challenge that these processes are aiming to address?

Poverty and food insecurity were widespread challenges that related to degradation, desertification and the inability of farmers to produce more than one crop per year.

Action: What did people do to address the challenges?

Government agencies promoted rational usage of soil and water resources by providing irrigation technologies to provide water for cropping in the dry season and thus enable increased cropping intensity.

Deep tubewell technology was introduced for irrigation using groundwater. The 1985 Barind Integrated Area Development Project was followed in 1992 by the Barind Multipurpose Development Authority (BMDA). Innovative management practices such as deep tubewells fitted with smart card–operated electric pumps were used to develop drought-resilient irrigation systems.

Following the installation of deep tubewells water was abstracted from a depth of 15-20 meters, and water was initially distributed through open channels. Later, these were fitted with smart card–operated electric/solar pumps and underground distribution pipes to develop a drought-resilient irrigation system.

By enabling cropping in the dry season, 15,800 deep tubewells have increased cropping intensity and reduced the cost of irrigation water for 1ha from about $400 to <$200. On the other hand, introduction of smart cards and buried pipelines for water distribution increased the efficiency of water use and facilitated revenue collection by the BMDA. However, abstraction of groundwater for irrigation triggered another issue – over exploitation of groundwater in the area, which in some cases has resulted in the abandonment of shallow tubewells previously used for drinking water.

In 2004 BMDA initiated a project to lift surface water from rivers in the area (the Padma/Ganges, Mahananda and Tangan) to water bodies in the irrigated areas . These sources supplement existing irrigation systems and also contribute to groundwater recharge. At the same time, usage of solar power has reduced the cost of pumping water. Previously derelict water bodies have become effective water reservoirs and plantations of trees and horticultural crops along roads and channels have transformed the land cover. Improved soil health has been achieved by application of compost.

BMDA's aim is to boost productivity in the drought affected Barind through its projects, and it has encouraged communities to adopt diversified land use in all seasons. Institutions such as the Department of Agricultural Extension and many NGOs promote a variety of seasonal, annual and perennial crops in the area, the use of balanced fertilizer, and establishment of high density fruit crops. The BMDA approach has greatly changed the drought-affected Barind.

Over recent years increased livelihood options and improved access to education, marketing, health services have enhanced the quality of life in the area. Technical support provided by BMDA and sound collaboration and coordination between actors has enabled farmers to enhance their knowledge of SLM and to improve market access. Overall, the approach has minimised loss of irrigation water and more recently also improved ground water recharge, although not to sustainable levels. The use of solar power for lifting water minimises use of non-renewable energy sources, and water meters minimise misuse of irrigation water.

Lessons learnt and recommendations:

These interventions contributed significantly to reducing poverty in the Barind region which became self-sufficient in the production of rice. Effective planning and governance have contributed to these successes. However, relatively short-term gains have come at the cost of long-term sustainability and equity.

Although this approach to addressing a complex set of challenges relating to sustainable land management in a changing climate embraced impressive innovations and has succeeded in the medium term, it also reflects how the solutions (in this case, land restoration and drought mitigation via deep tubewell irrigation of rice coupled with the restoration of productivity of land) may not be sustainable in the longer term. Farmers are now struggling to access groundwater in the dry season because of excessive extraction of this resource upon which all of the positive outcomes depend. Under conditions of climate change, designers and implementers of interventions intended to address the challenges of drought must consider the externalities that they may induce.

References

Assessment, M. E. (2005). Millenium ecosystem assessment. Ecosystem and human well-being: desertification synthesis. Washington, D.C., USA, World Resources Institute.

Ison, R. L., K. B. Collins and P. J. Wallis (2015). "Institutionalising social learning: Towards [1] United Nations Convention to Combat Desertification, 2022. The Global Land Outlook, second edition. UNCCD, Bonn.

[2] Mirzabaev, A., J. Wu, J. Evans, F. Garcia-Oliva, I.A.G. Hussein, M.H. Iqbal, J. Kimutai, T. Knowles, F. Meza, D. Nedjraoui, F. Tena, M. Turkeş, R.J. Vazquez, M. Weltz, 2019: Desertification. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Portner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.005

[3] Mirzabaev, A., J. Wu, J. Evans, F. Garcia-Oliva, I.A.G. Hussein, M.H. Iqbal, J. Kimutai, T. Knowles, F. Meza, D. Nedjraoui, F. Tena, M. Turkeş, R.J. Vazquez, M. Weltz, 2019: Desertification. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Portner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.005

[4] Smith, P., J. Nkem, K. Calvin, D. Campbell, F. Cherubini, G. Grassi, V. Korotkov, A.L. Hoang, S. Lwasa, P. McElwee, E. Nkonya, N. Saigusa, J.-F. Soussana, M.A. Taboada, 2019: Interlinkages Between Desertification, Land Degradation, Food Security and Greenhouse Gas Fluxes: Synergies, Trade-offs and Integrated Response Options. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Portner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)].
https://doi.org/10.1017/9781009157988.008

---

[1] Mirzabaev, A., J. Wu, J. Evans, F. Garcia-Oliva, I.A.G. Hussein, M.H. Iqbal, J. Kimutai, T. Knowles, F. Meza, D. Nedjraoui, F. Tena, M. Turkeş, R.J. Vazquez, M. Weltz, 2019: Desertification. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Portner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E.

Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.005

[2] Olsson, L., H. Barbosa, S. Bhadwal, A. Cowie, K. Delusca, D. Flores-Renteria, K. Hermans, E. Jobbagy, W. Kurz, D. Li, D.J. Sonwa, L. Stringer, 2019: Land Degradation. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.006

[3] Mirzabaev, A., J. Wu, J. Evans, F. Garcia-Oliva, I.A.G. Hussein, M.H. Iqbal, J. Kimutai, T. Knowles, F. Meza, D. Nedjraoui, F. Tena, M. Turkeş, R.J. Vazquez, M. Weltz, 2019: Desertification. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Portner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.005

[4] Mirzabaev, A., J. Wu, J. Evans, F. Garcia-Oliva, I.A.G. Hussein, M.H. Iqbal, J. Kimutai, T. Knowles, F. Meza, D. Nedjraoui, F. Tena, M. Turkeş, R.J. Vazquez, M. Weltz, 2019: Desertification. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Portner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.005

---

[1] Smith, P., J. Nkem, K. Calvin, D. Campbell, F. Cherubini, G. Grassi, V. Korotkov, A.L. Hoang, S. Lwasa, P. McElwee, E. Nkonya, N. Saigusa, J.-F. Soussana, M.A. Taboada, 2019: Interlinkages Between Desertification, Land Degradation, Food Security and Greenhouse Gas Fluxes: Synergies, Trade-offs and Integrated Response Options. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Portner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.008

[2] Mirzabaev, A., J. Wu, J. Evans, F. Garcia-Oliva, I.A.G. Hussein, M.H. Iqbal, J. Kimutai, T. Knowles, F. Meza, D. Nedjraoui, F. Tena, M. Turkeş, R.J. Vazquez, M. Weltz, 2019: Desertification. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Portner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E.

Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.005

[3] P.H. Verburg, G. Metternicht, C. Allen, N. Debonne, M. Akhtar-Schuster, M. Inácio da Cunha, Z. Karim, A. Pilon, O. Raja, M. Sánchez Santivañez, and A. Şenyaz. 2019. Creating an Enabling Environment for Land Degradation Neutrality and its Potential Contribution to Enhancing Well-being, Livelihoods and the Environment. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany.

[4] United Nations Convention to Combat Desertification, 2022. The Global Land Outlook, second edition. UNCCD, Bonn.

[5] Mirzabaev, A., J. Wu, J. Evans, F. Garcia-Oliva, I.A.G. Hussein, M.H. Iqbal, J. Kimutai, T. Knowles, F. Meza, D. Nedjraoui, F. Tena, M. Turkeş, R.J. Vazquez, M. Weltz, 2019: Desertification. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Portner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.005

[6] Mirzabaev, A., J. Wu, J. Evans, F. Garcia-Oliva, I.A.G. Hussein, M.H. Iqbal, J. Kimutai, T. Knowles, F. Meza, D. Nedjraoui, F. Tena, M. Turkeş, R.J. Vazquez, M. Weltz, 2019: Desertification. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Portner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.005

[7] A. Reichhuber, N. Gerber, A. Mirzabaev, M. Svoboda, A. Lopez Santos, V. Graw, R. Stefanski, J. Davies, A. Vuković, M.A. Fernandez Garcia, C. Fiati and X. Jia. 2019. The Land-Drought Nexus: Enhancing the Role of Land-Based Interventions in Drought Mitigation and Risk Management. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany.

[8] M.J. Sanz, J. de Vente, J.-L. Chotte, M. Bernoux, G. Kust, I. Ruiz, M. Almagro, J.-A. Alloza, R. Vallejo, V. Castillo, A. Hebel, and M. Akhtar-Schuster. 2017. Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany.

[9] Mirzabaev, A., J. Wu, J. Evans, F. Garcia-Oliva, I.A.G. Hussein, M.H. Iqbal, J. Kimutai, T. Knowles, F. Meza, D. Nedjraoui, F. Tena, M. Turkeş, R.J. Vazquez, M. Weltz, 2019: Desertification. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Portner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.005

[10] A. Reichhuber, N. Gerber, A. Mirzabaev, M. Svoboda, A. Lopez Santos, V. Graw, R. Stefanski, J. Davies, A. Vuković, M.A. Fernandez Garcia, C. Fiati and X. Jia. 2019. The Land-Drought Nexus: Enhancing the Role of

Land-Based Interventions in Drought Mitigation and Risk Management. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany.

[11] Smith, P., J. Nkem, K. Calvin, D. Campbell, F. Cherubini, G. Grassi, V. Korotkov, A.L. Hoang, S. Lwasa, P. McElwee, E. Nkonya, N. Saigusa, J.-F. Soussana, M.A. Taboada, 2019: Interlinkages Between Desertification, Land Degradation, Food Security and Greenhouse Gas Fluxes: Synergies, Trade-offs and Integrated Response Options. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Portner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.008

[12] Olsson, L., H. Barbosa, S. Bhadwal, A. Cowie, K. Delusca, D. Flores-Renteria, K. Hermans, E. Jobbagy, W. Kurz, D. Li, D.J. Sonwa, L. Stringer, 2019: Land Degradation. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.006

[13] United Nations Convention to Combat Desertification, 2022. The Global Land Outlook, second edition. UNCCD, Bonn.

[14] A. Reichhuber, N. Gerber, A. Mirzabaev, M. Svoboda, A. Lopez Santos, V. Graw, R. Stefanski, J. Davies, A. Vuković, M.A. Fernandez Garcia, C. Fiati and X. Jia. 2019. The Land-Drought Nexus: Enhancing the Role of Land-Based Interventions in Drought Mitigation and Risk Management. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany.

[15] M.J. Sanz, J. de Vente, J.-L. Chotte, M. Bernoux, G. Kust, I. Ruiz, M. Almagro, J.-A. Alloza, R. Vallejo, V. Castillo, A. Hebel, and M. Akhtar-Schuster. 2017. Sustainable Land Management contribution to successful land-based climate change adaptation and mitigation. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany.

[16] A. Reichhuber, N. Gerber, A. Mirzabaev, M. Svoboda, A. Lopez Santos, V. Graw, R. Stefanski, J. Davies, A. Vuković, M.A. Fernandez Garcia, C. Fiati and X. Jia. 2019. The Land-Drought Nexus: Enhancing the Role of Land-Based Interventions in Drought Mitigation and Risk Management. A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany.

African Development Bank Group. 2016. Jobs for Youth in Africa Strategy for Creating 25 Million Jobs and Equipping 50 Million Youth 2016-2025. https://www.afdb.org/fileadmin/uploads/afdb/Documents/Boards-Documents/Bank_Group_Strategy_for_Jobs_for_Youth_in_Africa_2016-2025_Rev_2.pdf

Bradford A., R. Proefke, A. Mugeere, and B. Stocking. 2021. Young people and climate change. The British Academy: COP26 Briefings.https://www.thebritishacademy.ac.uk/documents/3285/Young-people-and-climate-change.pdf

United Nations Convention to Combat Desertification. 2019. The Global Land Outlook, West Africa Thematic Report, Bonn, Germany. https://www.unccd.int/resources/publications/global-land-outlook-west-africa-thematic-report-land-degradation-neutrality

United Nations Convention to Combat Desertification. 2019. The Global Land Outlook, East Africa Thematic Report, Bonn, Germany. https://www.unccd.int/sites/default/files/2022-04/GLO%20East%20Africa%20report_WEB.pdf

Dupar M, Lovell E, Walmsley O, Diwakar V, Balcou C, Tesfaye B and Krishnan V. (2021) RESILIENT GENERATION: Supporting young people's prospects for decent work in the drylands of east and west Africa. SPARC & GAGE. https://www.sparc-knowledge.org/publications-resources/report-resilient-generation-supporting-young-peoples-prospects-decent-work

International Federation of Red Cross and Red Crescent Societies (IFRC). 2022. DROUGHT, DESERTIFICATION, DISPLACEMENT AND MIGRATION; Can Nature Offer Part of the Solution? https://preparecenter.org/wp-content/uploads/2022/06/Drought_NbS_final.pdf

Reed, M. and Stringer, L. (2016) Land Degradation, Desertification and Climate Change: Anticipating, Assessing and Adapting to Future Change. Routledge, London. https://doi.org/10.4324/9780203071151

von Keyserlingk, J., A. H. Thieken, and E. N. Paton. 2023. Approaches to assess land degradation risk: a synthesis. Ecology and Society 28(1):53. https://doi.org/10.5751/ES-13951-280153

World Bank, Climate Change Knowledge Portal. 2024. Country: Burkina Faso. https://climateknowledgeportal.worldbank.org/country/burkina-faso

Belmin, R., SawadogoMore, H. and N'Dienor, M. 2023. How the zaï technique is helping farmers adapt to climate change in the Sahel. https://www.weforum.org/agenda/2023/08/zai-technique-sahel-farmers-adapt-climate-change/#:~:text=The%20za%C3%AF%20technique%20is%20a,that%20collect%20and%20store%20rainwater.

World Bank, Climate Change Knowledge Portal. 2024. Country: Tanzania. https://climateknowledgeportal.worldbank.org/country/burkina-faso

Hopwood, C., J. Zizer, A. Nissen, C. Dillard, A. Thompkins, J. Graça, D. Waldhorn, and W. Bleidorn. 2024. Paradoxical gender effects in meat consumption across cultures. Nature Scientific Reports (14). https://www.nature.com/articles/s41598-024-62511-

3#:~:text=Across%20all%20countries%2C%20men%20tended,human%20development%20and%20gender%20equality

volume

ILO. 2022. Global Employment Trends for Youth 2022: Investing in transforming futures for young people. https://www.ilo.org/sites/default/files/wcmsp5/groups/public/@dgreports/@dcomm/@publ/documents/publication/wcms_853321.pdf

Further References

Archer, E. R. M., N. M. Oettlé, R. Louw and M. A. Tadross (2008). "'Farming on the edge' in arid western South Africa: climate change and agriculture in marginal environments." Geography 93(2): 98-107.

Ardo, J. and L. Olsson (2003). "Assessment of soil organic carbon in semi-arid Sudan using GIS and the CENTURY model". Journal of Arid Environments 54(4): 633-651.

Arnold, R.D & Wade, J.P. (2015) "A Definition of Systems Thinking: A Systems Approach". 2015 Conference on Systems Engineering Research. Procedia Computer Science Volume 44, 2015, Pages 669-678 https://pdf.sciencedirectassets.com/280203/1

Assessment, M. E. (2005). Millenium ecosystem assessment. Ecosystem and human well-being: desertification synthesis. Washington, D.C., USA, World Resources Institute.

Bawden, R.J. (1994) Creating Learning Systems: A Metaphor for Institutional Reform for Development. Chapter 35 In "Beyond Farmer First: Rural Peoples Knowledge, Agricultural Research and Extension Practice", I. Scoones and J. Thompson (Eds) Intermediate Technology Publications, London

Beg, N., J. C. Morlot, O. Davidson, Y. Afrane-Okesse, L. Tyani, F. Denton, Y. Sokona, J. P. Thomas, E. L. La Rovere, J. K. Parikh, K. Parikh and A. A. Rahman (2002). "Linkages between climate change and sustainable development." Climate Policy 2(2-3): 129-144.

Bolwig, S., S. M. Cold-Ravnkilde, K. Rasmussen, T. Breinholt and M. Mortimore (2009). Achieving sustainable natural resource management in the Sahel after the era of desertification markets, property rights, decentralisation and climate change. Copenhagen, Denmark, Danish Institute for International Studies: 66 pp.

Bolwig, S., S. M. Cold-Ravnkilde, K. Rasmussen, T. Breinholt and M. Mortimore (2009). "Achieving sustainable natural resource management in the Sahel after the era of desertification markets, property rights, decentralisation and climate change." Report, Danish Institute for International Studies(7): 66 pp.

Collins M., M. Sutherland, L. Bouwer, S.-M. Cheong, T. Frölicher, H. Jacot Des Combes, M. Koll Roxy, I. Losada, K. McInnes, B. Ratter, E. Rivera-Arriaga, R.D. Susanto, D. Swingedouw, and L. Tibig (2019). "Extremes, Abrupt

Changes and Managing Risk. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate" [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 589–655. https://doi.org/10.1017/9781009157964.008.

Committee', I. N. and f. t. e. o. a. i. c. t. c. d. i. t. c. e. s. d. a. o. d. p. i. Africa) (1994). United Nations Convention to Combat Desertification in those countries experiencing serious drought and / or desertification, particularly in Africa. International.

Darkoh, M. B. K. (1998). "The nature, causes and consequences of desertification in the drylands of Africa." Land Degradation & Development 9(1): 1-20.

Darkoh, M. B. K. (2009). "An overview of environmental issues in Southern Africa." African Journal of Ecology 47(s1): 93-98.

Desanker, P. V. and C. O. Justice (2001). "Africa and global climate change: critical issues and suggestions for further research and integrated assessment modeling." Climate Research 17(2): 93-103.

Descroix, L., G. Mahe, T. Lebel, G. Favreau, S. Galle, E. Gautier, J. C. Olivry, J. Albergel, O. Amogu, B. Cappelaere, R. Dessouassi, A. Diedhiou, E. Le Breton, I. Mamadou and D. Sighomnou (2009). "Spatio-temporal variability of hydrological regimes around the boundaries between Sahelian and Sudanian areas of West Africa: a synthesis." Journal of Hydrology 375(1-2): 90-102.

Falkenmark, M. and J. Rockstrom (2008). "Building resilience to drought in desertification-prone savannas in Sub-Saharan Africa: The water perspective." Natural Resources Forum 32(2): 93-102.

Farage, P. K., J. Ardo, L. Olsson, E. A. Rienzi, A. S. Ball and J. N. Pretty (2007). "The potential for soil carbon sequestration in three tropical dryland farming systems of Africa and Latin America: a modelling approach." Soil & Tillage Research 94(2): 457-472.

Geist, H. J. and E. F. Lambin (2004). "Dynamic causal patterns of desertification." Bioscience 54(9): 817-829.

Giannini, A., M. Biasutti and M. M. Verstraete (2008). "A climate model-based review of drought in the Sahel: desertification, the re-greening and climate change." Global and Planetary Change 64(3-4): 119-128.

Grainger, A., M. S. Smith, V. R. Squires and E. P. Glenn (2000). "Desertification and climate change: the case for greater convergence." Mitigation and Adaptation Strategies for Global Change 5(4): 361-377.

Hamandawana, H., M. Nkambwe, R. Chanda and F. Eckardt (2005). "Population driven changes in land use in Zimbabwe's Gutu district of Masvingo province: some lessons from recent history." Applied Geography 25(3): 248-270.

Hein, L. and N. de Ridder (2006). "Desertification in the Sahel: a reinterpretation." Global Change Biology 12(5): 751-758.

Hein, L., M. J. Metzger and R. Leemans (2009). "The local impacts of climate change in the Ferlo, Western Sahel." Climatic Change 93(3-4): 465-483.

Hellden, U. (2008). "A coupled human-environment model for desertification simulation and impact studies." Global and Planetary Change 64(3-4): 158-168.

Hellden, U. and C. Tottrup (2008). "Regional desertification: A global synthesis." Global and Planetary Change 64(3-4): 169-176.

Henderson-Sellers, A., P. Irannejad and K. McGuffie (2008). "Future desertification and climate change: the need for land-surface system evaluation improvement." Global and Planetary Change 64(3-4): 129-138.

Innes, J. L. and G. M. Hickey (2006). "The importance of climate change when considering the role of forests in the alleviation of poverty." International Forestry Review 8(4): 406-416.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp

IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (2019) [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, 755 pp. https://doi.org/10.1017/9781009157964.

IPCC, 2019: Summary for Policymakers. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)].

Ison, R. L., K. B. Collins and P. J. Wallis (2015). "Institutionalising social learning: Towards systemic and adaptive governance." Environmental Science & Policy 53, Part B: 105-117.

Kassahun, A., H. A. Snyman and G. N. Smit (2008). "Impact of rangeland degradation on the pastoral production systems, livelihoods and perceptions of the Somali pastoralists in Eastern Ethiopia." Journal of Arid Environments 72(7): 1265-1281.

Lal, R. (2001). "Potential of desertification control to sequester carbon and mitigate the greenhouse effect." Climatic Change 51(1): 35-72.

Lal, R. (2002). "Carbon sequestration in dryland ecosystems of West Asia and North Africa." Land Degradation & Development 13(1): 45-59.

Lal, R. (2003). "Global potential of soil carbon sequestration to mitigate the greenhouse effect." Critical Reviews in Plant Sciences 22(2): 151-184.

Lal, R. (2004). "Carbon sequestration in dryland ecosystems." Environmental Management 33(4): 528-544.

Lal, R. (2009). "Sequestering carbon in soils of arid ecosystems." Land Degradation & Development 20(4): 441-454.

Lebel, T., B. Cappelaere, S. Galle, N. Hanan, L. Kergoat, S. Levis, B. Vieux, L. Descroix, M. Gosset, E. Mougin, C. Peugeot and L. Seguis (2009). "AMMA-CATCH studies in the Sahelian region of West-Africa: an overview." Journal of Hydrology 375(1-2): 3-13.

LeHouerou, H. N. (1996). "Climate change, drought and desertification." Journal of Arid Environments 34(2): 133-185.

Lepers, E., E. F. Lambin, A. C. Janetos, R. DeFries, F. Achard, N. Ramankutty and R. J. Scholes (2005). "A synthesis of information on rapid land-cover change for the period 1981-2000." Bioscience 55(2): 115-124.

Lovett, J. C., G. F. Midgley and P. Barnard (2005). "Climate change and ecology in Africa." African Journal of Ecology 43(3): 167-169.

Low, P. S. (2005). Climate change and Africa. Cambridge, Cambridge University Press.

Macharia, P. N. (2004). "Community based interventions as a strategy to combat desertification in the arid and semi-arid rangelands of Kajiado District, Kenya." Environmental Monitoring and Assessment 99(1-3): 141-147.

Maranz, S. (2009). "Tree mortality in the African Sahel indicates an anthropogenic ecosystem displaced by climate change." Journal of Biogeography 36(6): 1181-1193.

Marks, E., G. K. S. Aflakpui, J. Nkem, R. M. Poch, M. Khouma, K. Kokou, R. Sagoe and M. T. Sebastia (2009). "Conservation of soil organic carbon, biodiversity and the provision of other ecosystem services along climatic gradients in West Africa." Biogeosciences 6(8): 1825-1838.

Milton, S. J., W. R. J. Dean and D. M. Richardson (2003). "Economic incentives for restoring natural capital in southern African rangelands." Frontiers in Ecology and the Environment 1(5): 247-254.

Mortimore, M. and B. Turner (2005). "Does the Sahelian smallholder's management of woodland, farm trees, rangeland support the hypothesis of human-induced desertification?" Journal of Arid Environments 63(3): 567-595.

Mougin, E., P. Hiernaux, L. Kergoat, M. Grippa, P. de Rosnay, F. Timouk, V. Le Dantec, V. Demarez, F. Lavenu, M. Arjounin, T. Lebel, N. Soumaguel, E. Ceschia, B. Mougenot, F. Baup, F. Frappart, P. L. Frison, J. Gardelle, C. Gruhier, L. Jarlan, S. Mangiarotti, B. Sanou, Y. Tracol, F. Guichard, V. Trichon, L. Diarra, A. Soumare, M. Koite, F. Dembele, C. Lloyd, N. P. Hanan, C. Damesin, C. Delon, D. Serca, C. Galy-Lacaux, J. Seghieri, S. Becerra, H. Dia, F. Gangneron and P. Mazzega (2009). "The AMMA-CATCH Gourma observatory site in Mali: relating climatic variations to changes in vegetation, surface hydrology, fluxes and natural resources." Journal of Hydrology 375(1-2): 14-33.

Msangi, J. P. (2004). "Drought hazard and desertification management in the drylands of southern Africa." Environmental Monitoring and Assessment 99(1-3): 75-87.

Mung'ong'o, C. G. (2009). "Political ecology: a synthesis and search for relevance to today's ecosystems conservation and development." African Journal of Ecology 47(s1): 192-197.

Nyssen, J., M. Haile, J. Naudts, N. Munro, J. Poesen, J. Moeyersons, A. Frankl, J. Deckers and R. Pankhurst (2009). "Desertification? Northern Ethiopia re-photographed after 140 years." Science of the Total Environment 407(8): 2749-2755.

Nyssen, J., J. Poesen and J. Deckers (2009). "Land degradation and soil and water conservation in tropical highlands." Soil & Tillage Research 103(2): 197-202.

Nyssen, J., J. Poesen, J. Moeyersons, J. Deckers, M. Haile and A. Lang (2004). "Human impact on the environment in the Ethiopian and Eritrean highlands - a state of the art." Earth-Science Reviews 64(3-4): 273-320.

Oba, G., R. B. Weladji, D. J. Msangameno, L. M. Kaitira and J. Stave (2008). "Scaling effects of proximate desertification drivers on soil nutrients in northeastern Tanzania." Journal of Arid Environments 72(10): 1820-1829.

Oettle, N., Ed. (2006). Knowledge and UNCCD: The Community Exchange and Training Programme. Governing Global Desertification: Linking Environmental Degradation, Poverty and Participation. Burlington, Ashgate.

Oettle, N. and B. Koelle (2015). Poverties and wealth: perceptions, empowerment and agency in sustainable land management. Land Restoration: Reclaiming Landscapes for a Sustainable Future. I. Chabay, M. Frick and H. Jennifer. Boston, Elsevier Inc.

Oettle, N., B. Koelle, S. Law, S. Parring, U. Schmiedel, E. Archer van Garderen and T. Bekele (2014). Participatory Adaptation Handbook - A practitioners guide for facilitating people centred adaptation to climate change. Cape Town Indigo development and change.

Olsson, L. and J. Ardo (2002). "Soil carbon sequestration in degraded semiarid agro-ecosystems - Perils and potentials." Ambio 31(6): 471-477.

Olsson, L., L. Eklundh and J. Ardo (2005). "A recent greening of the Sahel - Trends, patterns and potential causes." Journal of Arid Environments 63(3): 556-566.

Olukoye, G. A. and J. I. Kinyamario (2009). "Community participation in the rehabilitation of a sand dune environment in Kenya." Land Degradation & Development 20(4): 397-409.

Organisation for Economic Co-operation and Development. Development Assistance Committee. (2002). Creditor reporting system: aid activities. Aid activities targeting the objectives of the Rio Conventions. Statistics = Statistiques. Paris, Organisation for Economic Co-operation and Development: v.

Popp, A., S. Domptail, N. Blaum and F. Jeltsch (2009). "Landuse experience does qualify for adaptation to climate change." Ecological Modelling 220(5): 694-702.

Rasmussen, K., B. Fog and J. E. Madsen (2001). "Desertification in reverse? Observations from northern Burkina Faso." Global Environmental Change-Human and Policy Dimensions 11(4): 271-282.

Reynolds, J. F., D. M. Stafford Smith, E. F. Lambin, B. L. Turner, M. Mortimore, S. P. J. Batterbury, T. E. Downing, H. Dowlatabadi, R. J. Fernandez, J. E. Herrick, E. Huber-Sannwald, H. Jiang, R. Leemans, T. Lynam, F. T. Maestre, M. Ayarza and B. Walker (2007). "Global desertification: building a science for dryland development." Science 316(5826): 847-851.

Safriel, U. and Z. Adeel (2008). "Development paths of drylands: thresholds and sustainability." Sustainability Science 3(1): 117-123.

Schmiedel, U. (2006). Capacity development and scientist-land-user collaboration towards sustainable management of communal lands in southern Africa – creating initial structures. International Conference Soil and Desertification – Integrated Research for the Sustainable Management of Soils in Drylands, Hamburg, Germany.

Seely, M., E. Dirkx, C. Hager, P. Klintenberg, C. Roberts and D. von Oertzen (2008). "Advances in desertification and climate change research: are they accessible for application to enhance adaptive capacity?" Global and Planetary Change 64(3-4): 236-243.

Shukla, P.R., J. Skea, R. Slade, R. van Diemen, E. Haughey, J. Malley, M. Pathak, J. Portugal Pereira (eds.) Technical Summary. (2019). In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal

Pereira, P. Vyas, E. Huntley, K. Kissick, M, Belkacemi, J. Malley, (eds.)]. https://doi.org/10.1017/9781009157988.002

Sileshi, G., F. K. Akinnifesi, O. C. Ajayi, S. Chakeredza, M. Kaonga and P. W. Matakala (2007). "Contributions of agroforestry to ecosystem services in the miombo eco-region of eastern and southern Africa." African Journal of Environmental Science and Technology 1(4): 68-80.

Sivakumar, M. V. K. (2007). "Interactions between climate and desertification." Agricultural and Forest Meteorology 142(2-4): 143-155.

Sokona, Y. (2007). "Sub-Saharan Africa: combating desertification - the big challenge for the 21st century." Agriculture & Rural Development 14(1): 13-15.

Stephenne, N. and E. F. Lambin (2001). "A dynamic simulation model of land-use changes in Sudano-sahelian countries of Africa (SALU)." Agriculture Ecosystems & Environment 85(1-3): 145-161.

Stringer, L. C. (2008). "Reviewing the international year of deserts and desertification 2006: what contribution towards combating global desertification and implementing the united nations convention to combat desertification?" Journal of Arid Environments 72(11): 2065-2074.

Stringer, L. C., C. D. Dyer, M. S. Reed, A. J. Dougill, C. Twyman and D. Mkwambisi (2009). "Adaptations to climate change, drought and desertification: local insights to enhance policy in southern Africa." Environmental Science & Policy 12(7): 748-765.

Stringer, L. C., D. S. G. Thomas and C. Twyman (2007). "From global politics to local land users: applying the United Nations Convention to combat desertification in Swaziland." Geographical Journal 173: 129-142.

Tappan, G. and M. McGahuey (2007). "Tracking environmental dynamics and agricultural intensification in southern Mali." Agricultural Systems 94(1): 38-51.

Tappan, G. G., M. Sall, E. C. Wood and M. Cushing (2004). "Ecoregions and land cover trends in Senegal." Journal of Arid Environments 59(3): 427-462.

Taylor, C. M., E. F. Lambin, N. Stephenne, R. J. Harding and R. L. H. Essery (2002). "The influence of land use change on climate in the Sahel." Journal of Climate 15(24): 3615-3629.

Thomas, D. S. G., D. Sporton and J. Perkins (2000). "The environmental impact of livestock ranches in the Kalahari, Botswana: natural resource use, ecological change and human response in a dynamic dryland system." Land Degradation & Development 11(4): 327-341.

Tieszen, L. L., G. G. Tappan and A. Toure (2004). "Sequestration of carbon in soil organic matter in Senegal: an overview." Journal of Arid Environments 59(3): 409-425.

Tiffen, M. and M. Mortimore (2002). "Questioning desertification in dryland sub-Saharan Africa." Natural Resources Forum 26(3): 218-233.

Trumper, K., C. Ravilious and B. Dickson (2008). Carbon in drylands: desertification, climate change and carbon finance. A UNEP-UNDP-UNCDD Technical note for discussion at CRIC 7, Istanbul, Turkey - 03-14 November, 2008. Istanbul, Turkey, UNEP-WCMC: 12p.

Tschakert, P. (2007). "Views from the vulnerable: understanding climatic and other stressors in the Sahel." Global Environmental Change-Human and Policy Dimensions 17(3-4): 381-396.

Turner, M. D. (1999). "Conflict, environmental change, and social institutions in dryland Africa: limitations of the community resource management approach." Society & Natural Resources 12(7): 643-657.

Vagen, T. G., R. Lal and B. R. Singh (2005). "Soil carbon sequestration in sub-Saharan Africa: a review." Land Degradation & Development 16(1): 53-71.

Verstraete, M. M., A. B. Brink, R. J. Scholes, M. Beniston and M. S. Smith (2008). "Climate change and desertification: where do we stand, where should we go?" Global and Planetary Change 64(3-4): 105-110.

Verstraete, M. M., R. J. Scholes and M. S. Smith (2009). "Climate and desertification: looking at an old problem through new lenses." Frontiers in Ecology and the Environment 7(8): 421-428.

Vetter, S. (2009). "Drought, change and resilience in South Africa's arid and semi-arid rangelands." South African Journal of Science 105(1-2): 29-33.

Wittig, R., K. Konig, M. Schmidt and J. Szarzynski (2007). "A study of climate change and anthropogenic impacts in West Africa." Environmental Science and Pollution Research 14(3): 182-189.

IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001

(Bradford and al., 2021, and ILO, 2022)