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Current Opinion in Environmental Sustainability

How can we stop the slow-burning systemic fuse of loss and damage due to land degradation and drought in Africa?

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Droughts are extreme events that have major impacts on communities, ecosystems and economies due to slow onset and complex processes. Land and ecosystem degradation increase the risks of loss and damage during droughts, whereas well-adapted practices and policies can enable society to (re)build resilience. This review highlights actions needed to connect and fill gaps in the present systems for ecological and hydrological monitoring, governance, and alignment of economic incentives at regional, national and local scales. Stopping the slow-burning fuse of drought damage requires improved tracking and reversal of the observable slow-onset nature of hydrological and socio-economic drought. International scientific and technical cooperation to better map and quantify changing loss and damage risks could provide evidence-based action triggers.

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Current Opinion in Environmental Sustainability 2021, **50**:289–302

This review comes from a themed issue on **Slow onset events related to climate change**

Edited by **Susana Adamo**, **Riyanti Djalante**, **Prabodh GD Chakrabarti**, **Fabrice Renaud**, **Amsalu Woldie Yalew**, **Doreen Stabinsky**, and **Zinta Zommers**

Received: 21 June 2020; Accepted: 18 April 2021

https://doi.org/10.1016/j.cosust.2021.04.008

Introduction

Droughts are extreme events that have major impacts on communities, ecosystems and economies [1,2]. Vulnerability to drought can be exacerbated by land degradation, which is a slow onset phenomenon progressively reducing hydrological and ecological functions and productivity [3]. Whereas systemic degradation increases the risks of loss and damage during droughts, well-adapted sustainable land management practices and policies can enable society to (re)build resilience [4•]. Over the past decade, concerted international attention has been devoted to improving preparedness and response planning to reduce drought impacts on vulnerable populations [5], and adapting to the increasing frequency, duration and severity of droughts due to climate change. But until recently, far less attention has been paid to understanding, maintaining and boosting systemic resilience to drought in Africa.[7] This can be achieved through positive and proactive human interactions with the terrestrial life support system [6–9,10•] (Figure 1).

For many vulnerable people, living with unpredictable extremes has become 'normal'. As has the near impossibility of effective characterisation, monitoring and management of ecological and hydrological conditions due to a sparsity of long-term records from ground-based observation systems.[8] Continuous local observations by resource users have remained unrecorded or ignored. However, over the past decade, national and regional governance institutions and constitutional processes have begun to reconsider their resource management systems and capabilities.[9]

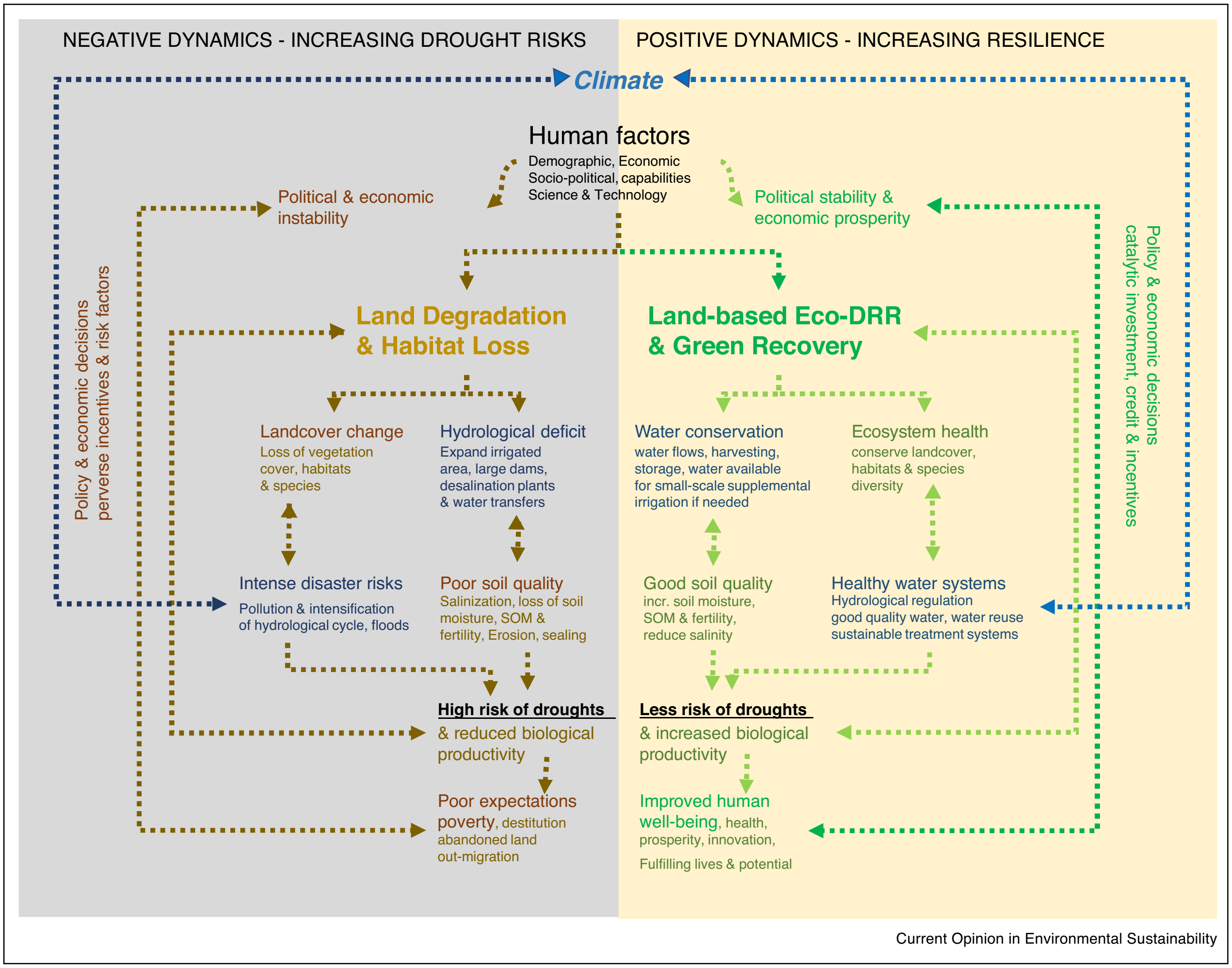
Global drought observation systems have evolved with increasing availability of technologies for remote sensing

[7] See, for example, East African countries progress reports at: https://resilience.igad.int/resources/ and West Africa progress report: http://www.cilss.int/index.php/note-dinformation-impacts-de-la-covid-19-sur-la-san/.

[8] See map of quality controlled rainfall stations in Africa in Ref. [11]. And also: http://agrhymet.cilss.int/index.php/bulletins/ and https://www.icpac.net/.

[9] See: www.unccd.int. An initial report on preparation of a stock-take assessment by the Intergovernmental Working Group on Drought is available at https://www.unccd.int/sites/default/files/sessions/documents/2020-12/ICCD_CRIC%2819%29_4-2015665E.pdf.

Figure 1



Simplified schematic view of drought and land degradation risks and resilience [based on range of sources including: Refs. 12–14].

[15] (Supplementary Figures 1 and 2). Furthermore, it is important to recognize that in an increasingly interconnected and interdependent world, additional scope still remains for mobile technologies to enable citizen science to further improve these systems [16,17]. In light of this, it is becoming more feasible to observe the linkages between slower onset land-based change processes (Supplementary Figures 3 and 4) and economic loss and damage during droughts [18] (Table 1). Over the coming decade, this should enable improved evidence to guide cooperation and investments to reverse slow onset change processes that exacerbate the risks to ecosystems and communities of avoidable loss and damage due to climate change.

The objective of this paper is to provide up to date knowledge and insights to the ongoing delivery of the work programme of the Warsaw International Mechanism (WIM) for Loss and Damage associated with Climate Change Impacts under the UNFCCC [19].[10] It presents an analytical review [drawing on recent assessments 4•,18,20] of the latest literature on land and ecosystem degradation in Africa and how this contributes to increasing immediate drought risks (alongside ongoing climatic changes). It highlights opportunities for enhanced national and international scientific and technical cooperation to evidence and further enable better-adapted land management practices and policies preventing loss and damage.

Effects of ecosystem degradation on risks of loss and damage during droughts in Africa

Disastrous drought events are characterised as slow onset disasters in the disaster management literature [25].

[10] See information at: https://unfccc.int/wim-excom.

Table 1

Translating observable characteristics of slow onset drought risk in Africa into cost implications for loss and damage (simplified from: Refs. [20–23])

	Land productivity / degradation	Stored water stocks	Dynamic water flows	Precipitation & Evapotranspiration
Physical observation of hazard & exposure	Land health & productivity in major biomes Agro-ecological zones/land suitability Land-uses & landcover	Soil moisture (column) Total Water Storage (GRACE) Groundwater monitoring & modelling Water storage & supply infrastructure	Runoff Streamflow Extent of surface water bodies	Precipitation Surface temperatures Soil moisture (surface) Evapotranspiration
Cost accounting	Effects on Gross Domestic Product (direct from affected sectors including agriculture, hydropower, tourism and indirect)	National natural capital accounts based on water balance accounting See FAO Aquastat & SDG 6.4.2	Cost of infrastructure to replace water supply and regulation of floods by ecosystem (and/or flood damage costs)	Cost of humanitarian drought relief (Post Disaster Needs Assessments, Insurance & Contingencies Funds)
Timeframe	*SLOW ONSET* ←———	———	———	———→ *RAPID ESCALATION*

However, the difference between the occurrence of uncharacteristically long dry spells[11] and disasters is critically important. Disasters only result from anomalous dry spells when there are insufficient reserves of water available within the exposed ecosystems and communities to withstand them. Hydrological and ecological processes (top L. in Table 1) that support and regulate water storage in man-made systems and the environment determine whether or not an unusual absence of rainfall results in disastrous drought impacts on individuals, society and the economy [26] (Lower R in Table 1). In light of this, essential adaptations can involve maintaining reserves of water, food and energy supplies as well as other ecosystem services and forms of capital (both natural and financial) in human settlements, crops, pasture, forests, and soils as well as surface and subsurface storage systems (amongst others).

Human, institutional and financial capabilities are needed to organize and manage the terrestrial ecosystems to buffer impacts on vulnerable individuals, social systems and economies [13,27,28]. Conflict resolution and cooperation are essential.[12] The slow onset of ecological and hydrological change processes provides opportunities for society to apply technical capabilities and avert the risk of disaster while rainfall conditions are still relatively normal. Only in cases where the society and its institutions either cannot or choose not to reverse the degradation and depletion of drought buffers do disastrous drought effects occur. A series of major global scientific reviews shed further light on the relationships between drought and the degradation of land and ecosystems in Africa [4,8,20,29,30,31•]. A well-cited recent example is the slow depletion of water reserves 2015–18 culminating in a drought crisis that disrupted water supplies to Capetown [32,33,34].[13]

A lack of information about the extent and value of the functioning economies and societies in drought-prone areas still limits the ability of governments to fully assess the loss and damages that affect national, regional, interregional and global economies when they break down [35].[14] Where human institutions and capabilities do not mediate effectively, observable, ecological and hydrological effects of drought translate directly into economic costs for the dependent households and societies [23,36–40] (Table 1). When goods, services and opportunities are destroyed by droughts, additional indirect knock-on and socially destructive multiplier effects are created within and beyond the regional economies [41,42]. Beyond

[11] This is known as 'meteorological drought', that is, a recurring natural phenomenon that is not in line with 'normal' meteorological patterns — and therefore difficult for meteorologists to predict.

[12] See,for example, pillar 1 of the Kenyan Common Programming Framework for Ending Drought Emergencies http://www.ndma.go.ke/index.php/resource-center/send/43-ending-drought-emergencies/4251-common-programme-framework.

[13] With hindsight, a fund for watershed restoration is now in place: https://panorama.solutions/en/solution/greater-cape-town-water-fund.

[14] Statistical systems to account the myriad of traded goods and services in the local economies of the marginal dry areas are improving. See: https://igad.int/programs/95-icpald/2576-igad-icpald-undertook-regional-virtual-meeting-on-africa-continental-free-trade-area-afcfta-agreement-to-help-member-states-optimize-benefits-from-livestock-products-18thnovember-2020, and the recently agreed revised UN System of Economic Environmental Accounts https://seea.un.org/ as well as further discussion in Ref. [21].

Table 2

Reported highlights from proactive land restoration achievements in West Africa [57]

Country	Achievements
Burkina Faso	COSOP-IFAD (2005–2012) created 247 boreholes, management of 72 560 ha of cropland including 2247 ha of lowlands, and use of improved techniques by 229 123 small farmers.
Republic of Mali	Traditional techniques (Zaï, stone barriers, earth bunds, half-moons, dune fixation, etc.) and agroforestry tested and disseminated by NRM programmes (CMDT, OHVN, ONG, etc.). 2000–2012 260 689 ha of degraded lands were reforested under the National Reforestation Strategy and Operation for a Green Mali.
Islamic Republic of Mauritania	Several hundred hectares of vegetation cover restored and protected in a participatory manner. Over 2000–12 reforested areas increased from 4530.78 ha–74 666.27 ha in 2012 31.0 ha of dunes stabilized.
Republic of Niger	The 3N Initiative (Nigeriens Nourish Nigeriens) under the Priority Investment Programme (PIP) recovered 254 536 ha out of 260 000 ha of degraded lands planned, that is, an achievement rate of 97.9%. 39 771 ha were stabilised out of 65 000 ha expected within five years (62.1% achievement rate). Coverage of 140 807 ha of plantation achieved against a forecast of 148 000 ha (95.1% achievement rate). Approx. 105 861 km of firebreaks completed over the 2011–2015 period. The area subject to assisted natural regeneration (ANR) in 2015 amounted to 48 091 ha against 21 938 ha in 2014, that is, a 119.2% increase, which shows the importance of assisted natural regeneration, mainly in the Maradi Region. The country's protected areas, which covered 6.6% of its surface in 2011, have increased to 14.29% of the national territory.
Republic of Senegal	Carbon credits generated an estimated 25 billion CFA Francs and stored 27 967 500 ton of carbon. Deferred grazing created 30 m^3/ha, or 900 000 m^3 of wood on previously bare land.
Federal Republic of Nigeria	1056 ha of degraded land restored in 2017 and 500 ha of land planted with six local species. Four native grass species have been introduced to provide fodder for livestock. AID-funded Fadama-III project-built wells, boreholes, increased irrigated area (153.92 ha) and trained more than 338 people in remediation techniques for degraded lands, seed treatment and planting by direct seeding.

recounting loss and damage costs for compensation, recent literature on resilience seeks to *reverse* these dynamics (see Figure 1) [e.g. Refs. 41,43,44].

Activating resilience through well-adapted land management practices and policies

A significant body of under-evaluated experience in (re) building resilience to drought does exist globally [20,45] and across Africa [29,46,47,48•,49–51] (Table 2). International scientific reviews [cited above and 52–55,56•] and other compilations of success stories [45,46][15] include drought risk reductions at different stages of the drought cycle (Table 3). Proactive reversal of the slower onset ecological and hydrological degradation affecting ecosystems and communities can be achieved through land management and ecosystem restoration practices (Figure 1). It is not the intention in this review to prescribe any particular one of these practices, but rather to affirm that land users explore and apply them (Table 2) alongside other social and institutional measures.

How can we reduce drought risks more effectively?

The reasons why resource users are able to apply land restoration practices successfully in some areas but not in others do not only depend on information that they have about local climate and other conditions, but often involve a complex mix of social, economic, financial legal or policy-related factors (Figure 1) [31•]. These can prevent vulnerable people from applying available resource management solutions. Policies and incentives at different scales (Table 4) can alter these barriers. From the emerging body of evidence on land restoration to reverse the deepening drought risks due to climate change, the following three key opportunities for proactive planning and policies already stand out:

- Aligning economic incentives enabling land users' restoration practices (Section 'Aligning economic incentives enabling land users' restoration practices')
- Integrating ecological and hydrological monitoring and assessment capabilities with socio-economic decision-support systems to guide planning and budgeting (Section 'Integrating ecological and hydrological monitoring and assessment capabilities with socio-economic decision-support systems to guide planning and budgeting')
- Multi-scale governance systems (from local-national-regional-global scales) (Section 'Multi-scale governance systems (from local-national-regional-global scales)')

A brief review of each of these is provided in the following sections, together with a referenced example of each.

Aligning economic incentives enabling land users' restoration practices

At the national level, governments readily take action to prevent drought risks from affecting the most productive sectors — such as power generation, and high value exports. However, it can be harder for politicians to justify

[15] See also: https://knowledge.unccd.int/drought-toolbox; https://www.droughtmanagement.info/; https://www4.unfccc.int/sites/NWPStaging/Pages/Documents-and-other-resources.aspx.

Table 3

Opportunities for proactive drought risk mitigation early on in the drought cycle [modified from https://knowledge.unccd.int/drought-toolbox and Ref. 58 for FAO and IDMP (forthcoming)]

Mitigate risks		Prepare	Response & recovery				Learn
Assess	**Prevent**	**Prepare**	**Pre-alert**	**Alert**	**Emergency**	**Recovery**	**Adapt**
i. High level review of policy & decision-making systems, and future risks	i. Boost current decision-making systems and adjust future plans	i. Put in place monitoring and Early Warning Systems	i. Promote low cost voluntary actions by water users	i. Restrict non-essential water uses	i. High cost direct demand restriction incl. urban users.	i. Monitor resource and learn lessons	i. Plan zonation of future developments.
ii. Sectoral reviews of infrastructure, incl. power supplies, maintenance and other risks	ii. Maintain infrastructure, ensure power supplies, – fix leaks, and so on.	ii. Identify and develop additional reserve capacity (incl. transfers, groundwater, desal.	ii. Ensure and prepare infrastructure to prioritize essential water needs	ii. Revise tariff on non-essential water use.	ii. Infrastructure responses incl. water transfers, trucking.	ii. Declare end of Drought — Norms reinstated	ii. Develop risk acceptance and awareness
iii. Sectoral reviews of agriculture drought risks in production systems	iii. Reinforce drought-smart production systems	iii. Reform abstractions of water and align agricultural use	iii. Increase communication and awareness	iii Review readiness for emergency	iii. Emergency supplies or losses of crops and needs to compensate	iii. Temporary restrictions, restore and restock water reservoirs and soils	iii. Embed a process of ongoing learning and adaptation of production systems
iv. Sectoral reviews of water mgt incl., recharge patterns, risks & options	iv. Restore recharge patterns, and catchment management practices	iv. Plan water allocation and sharing at catchment levels	iv. Ensure normal water sharing rules in effect, encourage voluntary water trading	iv. Water sharing rules change, water value/prices and trading increase	iv. Temporary unsustainable extractions to meet emergency needs	iv. Rehabilitate & refill reservoirs	iv. Re-evaluate capacity needs for watershed mgt incl. flood mgt
v. Sectoral reviews of risks to habitats supporting hydrological processes	v. Maintain and restore habitats & hydrological processes	v. Community engage in assessing risk & resilience of systems	v. Protect key habitats incl. species at risk by legislation or other	v. Ensure minimum environmental flows	v. Save certain species, for example, translocate	v. Monitor habitats recovery and promote habitat restoration	v. Model & report effects on water bodies & habitats under stress
vi. Implementation reviews of local risk awareness and responsible institutions	vi. Reinforce local awareness and responsible institutions	vi. Communicate priorities and risk awareness	vi. Intensify local monitoring of scenarios	vi. Communicate alert to govt & all other stakeholders	vi. Ensure response reaches all vulnerable	vi. Ensure response reached all vulnerable & assess recovery needs	vi. Promote local understanding of co-dependence on ecosystems
vii. Review finance mechanisms (local, national & global)	vii. Adjust and replenish funds and mechanisms	vii. Prepare results monitoring of financing in place	vii. Refresh training for all staff and inform public	vii. Ready emergency disbursement and results monitoring	vii. Emergency disbursement and monitoring	vii. Conclude emergency disbursement. Fund recovery needs	vii. Assess results from monitoring systems

major investments in sectors that are not perceived by their popular support bases to generate significant tax revenues or other immediate benefits. In many parts of Africa, both environmental conservation, water management and supply to vulnerable populations are still dependent upon external revenue generation and institution-building [59]. Enabling private individuals and businesses to engage profitably (Figure 2) not only reduces beneficiaries' and governments' dependence on external support, but helps to sustain and replicate successes.

Payments for Ecosystem Servies (PES) that reward community members with food, cash, rights to resource use, or other social benefits for labour-intensive watershed restoration, digging wells, constructing bunds, planting trees, and so on, build on long-established social traditions in Africa [e.g. Refs. 47,48•,61–63]. Governments and communities can recognize the role of upstream ecosystem health in securing downstream water supplies and increase these incentives for land restoration [64]. New PES models include carbon credits (Table 2), wildlife conservation and water funds, for example, in Kenya [65–68][16] and South Africa [34,69]. Where downstream water supplies generate hydropower (as in the Volta basin, and

[16] See also new Water Fund for Eldoret, Kenya: https://www.thegef.org/project/eldoret-iten-water-fund-tropical-water-tower-conservation.

Table 4

Typology of proactive land management measures across sectors and scales [partially based on: Ref. 52 p. 62]

Scale	Land use type	Land/ecosystem management measures
Field level		Managing extraction to maintain minimum flows to vulnerable communities and ecosystems
	Water bodies	Regulation of polluted discharges/water quality management
		Use or non-use of wells, artesian or with pumping systems
		Access to services (food distribution, water supply, health centers)
	Built environment	Construction siting and practices for cooling, ventilation, access to clean water, waste management and removal
		Water and food storage, cycling, treatment
		Vegetation management for shade and air conditioning
		Regulating access to water & energy sources
	Rangelands[a]	Seasonal/rotational grazing & mobility
		Supplementing fodder production, storage and distribution
		Reseeding/vegetation management
		Forest Reserves (incl. PAs w/ sustainable forest/natural resources)
	Tree-based saystems	Afforestation & Reforestation
		Agroforestry
		Improved vegetation management
		Improved water management/irrigation
	Cropped lands	Control soil erosion
		Integrated soil & fertility management[b]
Watershed/catchment		Integrated watershed management
		Afforestation/conservation of forest cover
	Mix of types listed above	Water harvesting [45] & recharge
		Maintain ecological water requirements
Regional/landscape		Ecosystem management & classification
		Power lines and grid management
		Paved roads & transportation systems
	Mix of types listed above	Transhumance corridors (people & livestock)
		Wildlife conservation, protected areas (PAs)
		Transfers/markets for water & food
		Telecommunications, radio & internet access
National		Agricultural subsidies & incentives/PES, credit & extension/agricultural advisory programmes
		Emergency preparedness and response, social security, insurance
	Any/all	Integrated land-use planning, sustainable & inclusive access to land, responsible land governance & tenure security, & taxation
Multi-nation/regional		Transboundary cooperation/border management,
	Any/all	Surveillance, security & peacekeeping
		Access/movement of people, goods, customs
Multi-lateral/global		Global Climate Finance
		Global Green Finance & Risk Insurance
		Environmentally Sustainable Trade Policies
	All	Negotiated global compensation mechanism for worsening loss and damage to land due to droughts and other climate extremes (-WIM)
		Other possible legal measures based on Polluter Pays principle

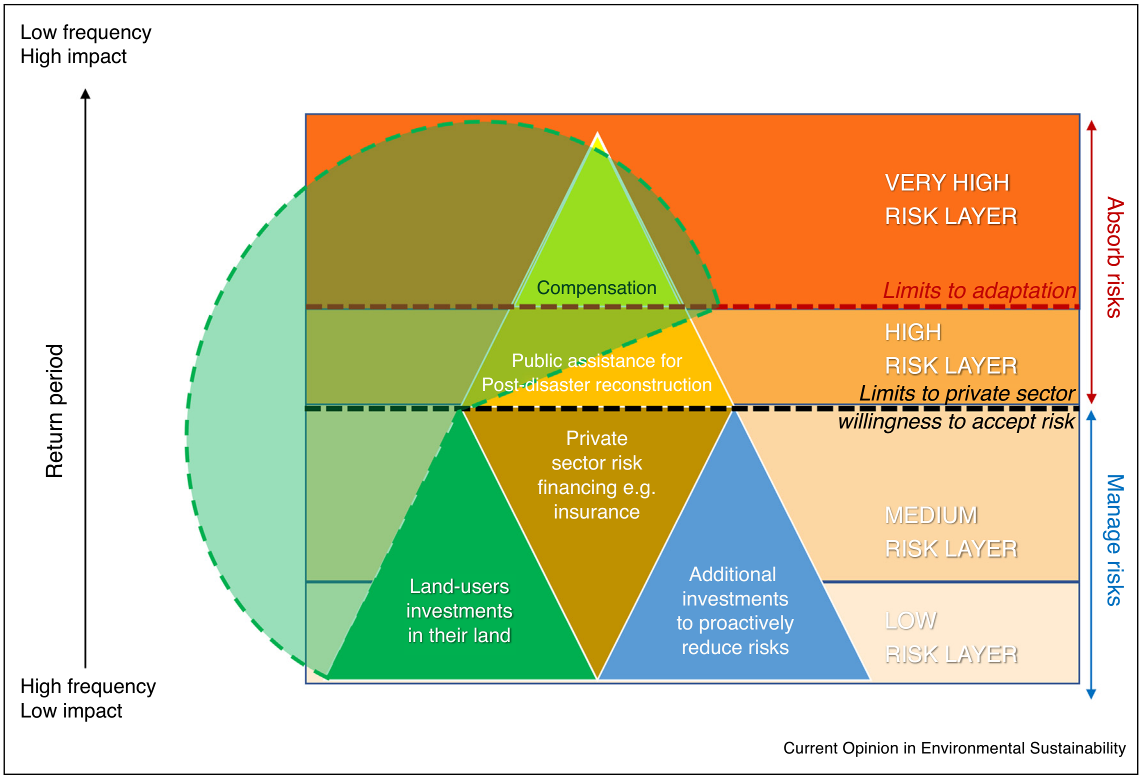
[a] See Ref. [116••].
[b] Soil water holding capacity increases with increasing Soil Organic matter (SOM). Therefore, where landuses conserve or add SOM, this can increase soil water holding capacity. Relevant practices can include reduced soil tillage systems, crop residue return or manipulations of residue quality in conjunction with soil redox potential. For further detail, see Ref. [46].

others), riparian countries also share power supplies at low tariffs.

A second opportunity for governments to increase market incentives for drought-smart production with less water demands and polluting emissions concerns trade conditions [70,71]. At the present time, tracing export products to production systems with light ecological footprints and positive feedbacks is mostly not feasible due to lack of environmental monitoring and certification systems. However, recent growth in international and local markets for climate(/drought)-smart products from recognisably drought-tolerant African trees, such as the *Senegalia senegal* (L.) Britton [72], *Adansonia digitata* (Baobab) and others [73] has enabled agricultural research and extension workers in Senegal to increase returns for land-users restoring trees to deforested silvopastoral areas [74•,75,76•,77–79]. These are immediately available to land-users as income from the sales of non-timber forest-products and fodder for livestock.[17]

[17] For similar in Kenya, see: https://www.thegef.org/project/restoration-arid-and-semi-arid-lands-asal-kenya-through-bio-enterprise-development-and-other.

Figure 2



Land users can invest more in restoration where risks are low and returns are regular [modified for FAO/IDMP forthcoming from: Refs. [60,117,118].

Integrating ecological and hydrological monitoring and assessment capabilities with socio-economic decision-support systems to guide planning and budgeting

Ecosystem processes whereby vegetative cover and land management practices create drought-resistant microclimates and improve soil conditions are observable by resource users at the field scale [see e.g. Refs. 80,81]. But effects on water supply and other ecosystem services such as cooling, increased regulation and storage of water and nutrients in soils and waterbodies generated by the increased tree-cover (see Box 1) are rarely measured and valued [82,83].[18] These and other largescale ecological and hydrological feedbacks between soil and vegetation conditions, cloud convection patterns and precipitation regulate or intensify both drought and flood risks in the Sahel [84–90].

Relationships that are believed to exist between changing vegetation cover types, surface runoff, recharge and water storage patterns [68,91] are complex. Remote sensing and modelling tools observing the Sahel [92][19] and Horn of Africa,[20] generate interesting hypotheses concerning possible effects on ecological and hydrological feedbacks from investments in land and water management [92–94,95•,96•,97], including those intended to achieve a Great Green Wall across the Sahara [9,96•,98]. These could help landusers to prevent dry spells from causing disasters. However, because ground-based monitoring networks in the Sahel remain sparse[21] (Supplementary Figure 5) challenges remain at the ground level to track and manage effects on water stored and circulating through vegetation, soils, aquifers, reservoirs and water bodies.

[18] See broader ongoing discussion of agricultural value chains for resilience in the Senegalese National Strategy for Land Degradation Neutrality https://knowledge.unccd.int/sites/default/ files/ldn_targets/2018-12/Senegal.pdf translating into actions funded by GEF: https://www.thegef.org/project/food-iap-agricultural-value-chains-resilience-support-project-parfa and GCF: https://www.greenclimate.fund/document/scaling-resilience-africa-s-great-green-wall-suraggwa.

[19] http://agrhymet.cilss.int/index.php/bulletins/.

[20] https://www.icpac.net/.

[21] See map of current Aghrymet hydrological monitoring network in: http://agrhymet.cilss.int/wp-content/uploads/2018/12/Bulletin-mensuel-Septembre-2020.pdf p4 and International Soil Moisure network: https://www.geo.tuwien.ac.at/insitu/data_viewer/.

Local capabilities to identify and map water resource conditions and features are supported with relevant mobile tools and technology transfer in a few areas[22] [99•]. National and local governments could make more systematic use of these to enable local resource managers to guide national planning, implementation and evaluations of drought risk reduction [100,101].

Multi-scale governance systems (from local-national-regional-global scales)

Aligning resource management practices, monitoring systems and resilience-building support requires effective communication and cooperation between stakeholders at the different levels of government and beyond (Supplementary Figure 6). For example, to design drought resilient improvements to water supply systems requires national governments to identify, finance, regulate and build the capacities of local service providers [102]. Affected households often know and could show governments and external partners who and what works (or not) on the ground to reduce drought risks [103]. But where there are no mechanisms for the local and national governments to record, cross-check and learn from such feedback, and local populations cannot hold them properly to account, then improvements are unlikely to be made [104,105].

Affected households can sometimes organize themselves to collectively manage the sustainable use of water resources and to claim their rights to access water, manage forests and grazing resources and maintain healthy urban living environments. They do this via local associations, cooperatives, labour unions, and others connecting to the government administrations at municipality and other levels. The systems through which information and support for drought risk reduction travels between local governments and associations and actors at other levels are regulated through national policies (see Supplementary Tables 1–3). These planning and policy frameworks also guide and inform the design of assistance from bilateral, inter-regional and global multilateral programmes for drought risk reduction alongside other climate-related risks (Supplementary Figure 6 and Box 1).[23]

Global governance processes are gradually putting in place systems to track and reduce the growing extent of exposure to drought risk that is due to land degradation (Sustainable Development Goal (SDG) 15.3.1) and water stress (SDG 6.4.2) [102],[24] and to help the least-developed countries to risk-proof these and other goals. These developments could help to reinforce risk governance for ecological and hydrological reserves, flag stages in rising drought risk due to degradation of these, and define triggers for management actions needed. To achieve this will require citizen science, extension support and technical exchanges to drive the creation of ground level monitoring systems to supplement the current use of

Box 1 Forest and rangeland degradation, restoration and adaptation to drought risk in Kenya

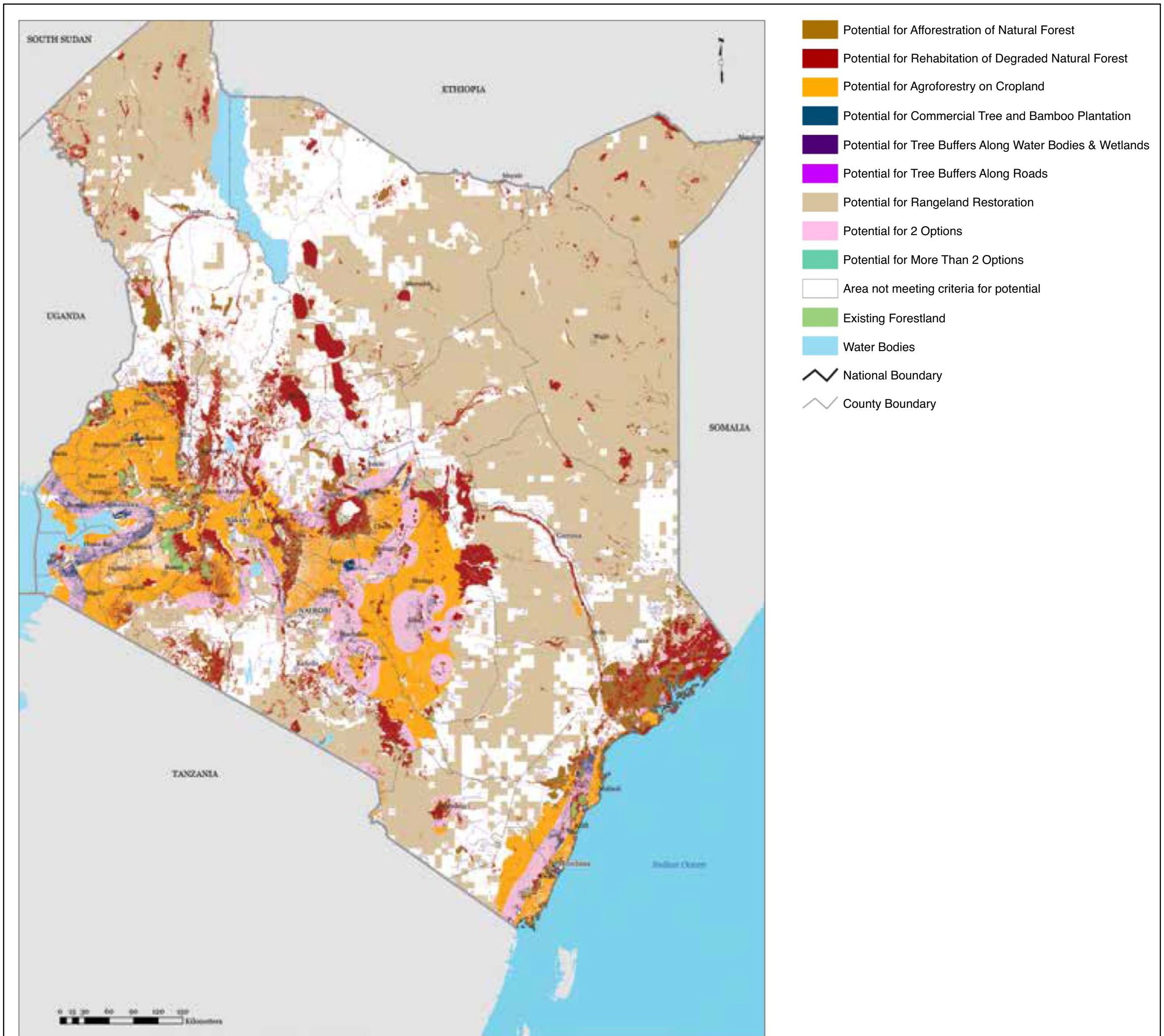
50 000 ha of timber and fuelwood worth (US$ 17 million were removed annually from Kenya's montane forests 2009–10 [108]. This resulted in loss of water quantity and quality, affecting productive sectors such as power, agriculture and fisheries, and increasing costs for water treatment and increased incidence of malaria — estimated at KES 3 700 million (US$ 46 million) per year. The inter-dependencies amongst sectors of the economy multiplied the total cost to KES 5 800 million (US$ 72 million) per year [68].

With each year of reduced water capture and regulation services provided by the forest, the risks of drought affecting downstream ecosystems increase. Comparison of river flow data to remotely sensed observation of forest cover losses confirms effects on water supply and other ecosystem services [109]. Downstream river flows support human life and sustain grazing in rangelands during drought. Where these are affected by upstream degradation and water extractions, vulnerability to drought increases downstream. A Post-disaster needs assessment following the 2009–11 drought counted costs including trucking emergency water and food supplies as well as loss of livestock and livelihoods, particularly in these areas [110]. Cross-sectoral economic effects were estimated to reduce GDP by 2.8% per year.

Recent studies demonstrate that investments in rangeland management can avoid and reverse some of these losses [21,111,112]. A recent model hypothesized that supporting land-users' investments in agroforestry and water storage could be expected to reduce vulnerability to drought in the drier catchments and across the Horn of Africa—lowering domestic water deficits by 54–100% and increasing per capita income by 285% over a 10-year period [62]. Further investigation is ongoing.[25] The national strategy for landscape restoration [67,113] (Figure 2), includes rangelands and forests in two drought-prone watersheds (Ewaso Nyiro North Catchment/ Lak Dera 2[26] and Tana River basin[27]), with support from GCF[28] [111], amongst a range of different land uses identified in other landscapes under the Bonn challenge and AFR100 initiatives. The government tracks natural capital gains and losses through its statistical systems [68][29] and periodically reviews its common programming framework on drought.

[22] See examples at: https://qcat.wocat.net/af/accounts/user/5747/.
[23] Some mapping of this support is compiled at http:/ /3w.igad.int/map/ and http://www.ndma.go.ke/index.php/ede/ investments-tracker.
[24] https://unstats.un.org/sdgs/indicators/database/.
[25] https://www.eld-initiative.org/en/news/news-detail/news/regreening-africa-kenya-dissemination-workshop/.
[26] See: http://ndma.go.ke/index.php/resource-center/send/67-case-studies/5231-isiolo-county-keeping-needy-students-in-school-with-food-for-fees and https://qcat.wocat.net/ar/accounts/user/5747/.
[27] See: https://www.ndma.go.ke/index.php/success-stories/108-building-community-resilience-to-drought-one-water-pan-at-a-time.
[28] see: http://ndma.go.ke/index.php/resource-center/send/42-special-reports/5201-twende-esmf.
[29] See the Kenyan government comments on the https://seea.un.org/content/global-consultation-complete-draft and national submission in the area of water and ecosystems: http://www4.unfccc.int/Submissions/Lists/ OSPSubmissionUpload/257_267_ 131301063961586743-Kenya%20submission% 20NWP_%20ecosystems%20and%20water%20resources.pdf. Also recent comments on the Interim Report of the Dasgupta Review: https://www.youtube.com/watch?v=Epueu2QO6-4.

Figure 3



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Potential for land restoration in Kenya [113].

remotely sensed meteorological observations, forecasting and indices [as in Refs. 10•,106•,107] (Figure 3).

Remaining needs for action to connect and fill gaps in the present systems

This review has highlighted particular opportunities for restorative action to prevent land and ecosystem degradation from multiplying drought effects. It explores the possible alignment of economic incentives for ecosystem restoration with ecological and hydrological monitoring and assessment and multi-scale governance and financing. Through the Adaptation Fund, Green Climate Fund and others, billions of dollars have been committed to international climate finance, expanding meteorological forecasting and its integration with remote earth observation capabilities to observe drought risks. Emerging national environmental economic accounting may now also begin to help further to translate changes in ecological and hydrological conditions into economic terms for decision-makers.

Still there is no effective support in place connecting vulnerable communities' observations of the essential basic functions and health of ecological and hydrological life support systems to national and global systems for action. This missing link is important because although these conversions are intuitively understood at the level of affected households and communities, statistics and evidence are still needed to improve national and global decision-making and trigger effective action on the ground. Enhanced international scientific and technical cooperation focusing on the levels of essential hydrological reserves in soil, water bodies and storage systems should provide the missing evidence to verify the effects of investments and guide human institutions and decision-making to avoid disasters occurring due to droughts.

WIM [19] offers vulnerable populations the prospect of recourse against governments that fail to avert, minimize and address losses and damages resulting from the adverse effects of climate change on extreme weather, such as droughts and other associated slow onset phenomena. However, vulnerability to drought is also exacerbated by human inactions and actions that directly degrade the functions of ecosystems and their services [13,28,114]. WIM is not designed to focus on addressing these — but through its consideration of slow onset events it can help to put adequate systems in place to determine the losses due to climate change and other drivers. Available human capacities for evidence-based action could then stop the slow-burning fuse of hydrological and ecological drought damage and disasters from affecting households and economies.

Conflict of interest statement

Nothing declared.

Acknowledgements

The authors would like to thank their institutions for support during the preparation of the paper. We would like to thank Stephen Adaawen, the members of the Intergovernmental Working Group on effective policy implementation measures for addressing drought under the UNCCD and the interagency Integrated Drought Management Programme for interesting and relevant discussions. We also thank the Editors and reviewers for their support. No dedicated funding source supported the preparation of the manuscript. The views expressed in this publication are not necessarily those of any agencies or individual involved. The designations employed in the paper and the presentation of material therein do not imply the expression of any opinion whatsoever on the part of the UN agencies. Unless otherwise indicated, the ideas and opinions expressed by the contributors do not necessarily represent the views of their employers. The authors would welcome being notified of any remaining errors identified that the editing process might have missed.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.cosust.2021.04.008.

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