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WASAG | The Global Framework on Water Scarcity in Agriculture

THINKING AHEAD
DROUGHT RESILIENCE AND COVID-19

WASAG WORKING PAPER

WASAG WORKING GROUP ON
DROUGHT PREPAREDNESS

Thinking ahead Drought resilience and COVID-19

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Introduction

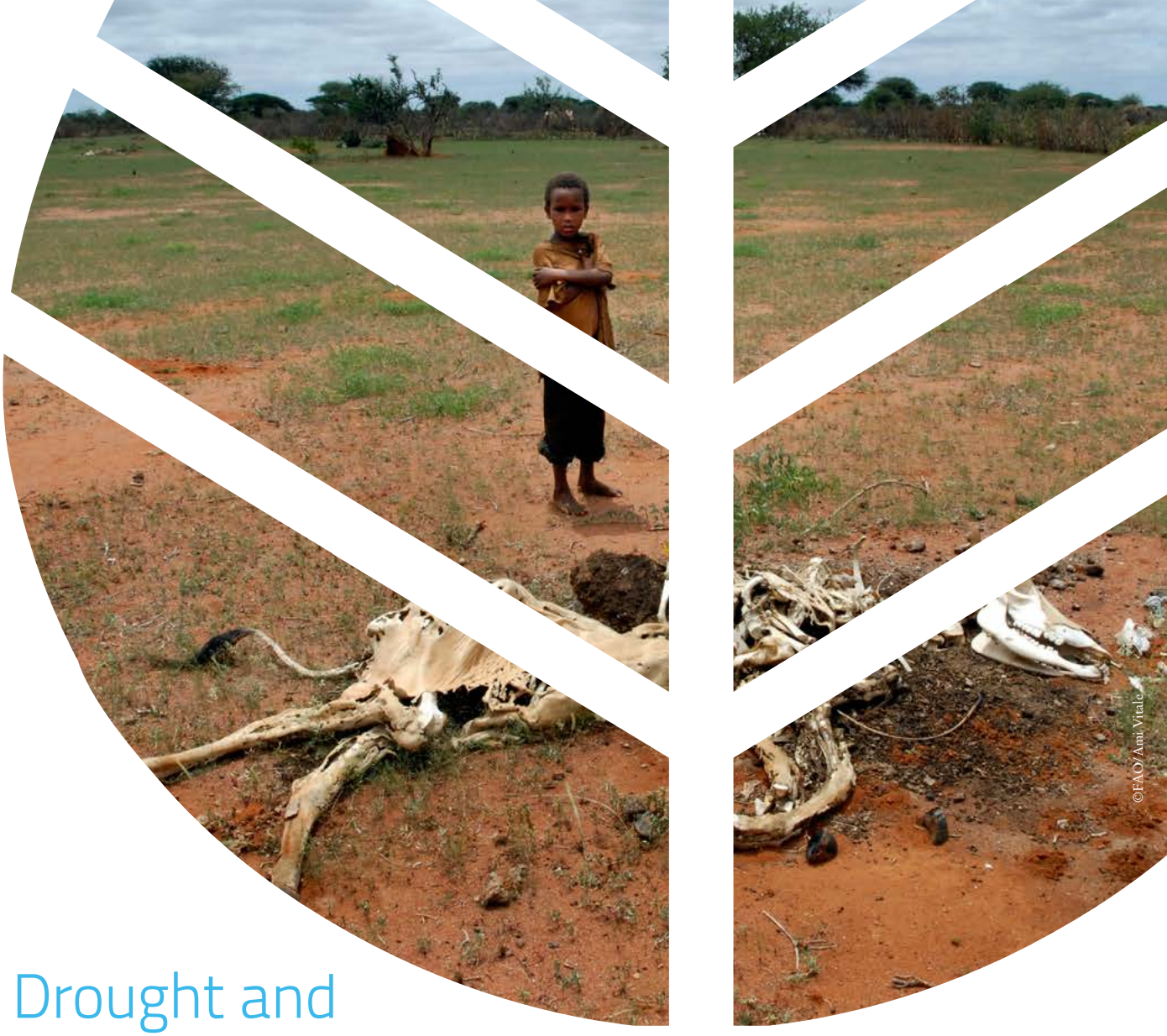
COVID-19 is a defining moment for strengthening drought resilience of society and managing ecosystems more sustainably. Both recent and historical experiences indicate that disease outbreaks very often follow extreme weather events. Drought, combined with other ecosystem changes such as habitat degradation, preceded the COVID-19 outbreak and has been associated with many other types of epidemics in the past. This paper highlights that the interactions between human, ecosystems and ecology often govern drought-linked disease. Factoring these interactions and their impacts on vulnerable communities and their environment is important for drought preparedness, resilience, and recovery. It also calls for increased investments and defines important steps for government and international agencies in responding to post COVID-19 period and in building back better for a more drought-resilient society and ecosystems. These steps require cross-sectoral, inter-disciplinary cooperation that responds to and addresses the underlying causes behind future disease outbreaks for a healthy living.

Commonly, such interventions aim to produce more output for the same or less level of input at the plot level. This objective itself may be adequate. However, water productivity interventions can have multiple objectives apart from reducing

the impacts of water scarcity. These interventions may be sought to, inter alia, raise farm-level income, alleviate poverty, increase crop diversification, and support water reallocation from agriculture to other sectors including the environment (Molden *et al.,* 2010; Giordano *et al.,* 2017). Moreover, different actors may have different intentions, perspectives, and scales of interest. Breeders, driven by scientific crop improvements, often focus on individual plant productivity enhancements. Farmers, needing to support livelihoods, focus at the farm-scale on maximizing incomes and food security for their immediate households. Public water resources managers, driven by long-term sustainability concerns, focus at the basin, national, or regional scales. Assessing the effectiveness of any water productivity intervention must start with understanding their defined objectives and the metrics considering the scale of the intervention.

To complicate matters, there are often inconsistencies, ambiguities, and misconceptions with water productivity terminology. This is important as it prevents actors from developing a shared understanding and vision of the issues at stake and of the objectives of the proposed interventions. Definitions have been developed from various academic fields each with different perspectives. For example, an engineer defines water "lost" when it flows beyond its system boundary, whereas a hydrologist sees this as not a "loss", but instead a "source" to an aquifer, wetland or for evaporation (Perry *et al.*, 2017). The terminology utilized can also be ambiguous. For example, "water use" is commonly said; however, the distinction between water "use" and water "consumption" is essential to the management of the total resource. Water productivity terms can also be misleading. For example, a common misperception is that water productivity interventions result in water "savings" at larger scales. Determining water "savings" is much more complex as it requires an understanding of the broader hydrological context and respective water accounts across scales (Grafton *et al.*, 2018).

Despite these challenges, are there common guiding principles to help policymakers and involved professionals to design interventions that minimize the impacts of water scarcity on food security, and vice versa? The aim of this paper is to summarize the experience with water productivity interventions observed in the field, to better understand the perspectives and scales of different actors, and to synthesize some key principles to follow. These recommendations will help policymakers and stakeholders more positively address the title of this paper.



Drought and infectious diseases

Infectious disease outbreaks[1] are often related to extreme weather events (floods, extreme heat, hurricanes, etc.) (McMichael, 2015) due to interacting social, ecological and environmental processes. Droughts can disturb the delicate balance of the host species and their ecology (da Silva *et al.*, 2013) and it can contribute to infectious diseases (Stanke *et al.*, 2013). The coincidence of drought preceding a pandemic only indicates a correlative rather than a causal relationship (Stanke *et al.*, 2013). The impact of drought on the environment and ecosystems is complex, making it difficult to pin-point the role of drought versus other environmental change drivers on zoonotic disease epidemics and pandemics. Further, inadequate longitudinal information on disease incidence and environmental change also hampers the efforts in exploring this relationship. Nevertheless, more data driven research is needed to establish the relationship and to understand more how drought influences the ecological and the ecosystem processes governing pathogen outbreaks in humans (Stanke *et al.*, 2013).

[1] Outbreaks are different in nature depending on the scale it is referred to as epidemic when the outbreak is out of control and is limited to a geographical region or community or a population. Pandemic is usually referred to outbreaks affecting several countries and a larger population.

Drought is often viewed as a local phenomenon, but it can cause ripple effects on a larger spatial scale as it interacts with human-induced changes in land tenure, urbanization, domestication of animals, unenforced forest management, fragmentation of land, intensification of agriculture, degradation of land and expansion of desertification. In recent years `flash droughts´ are also becoming more common (Pendergrass *et al.*, 2020; Otkin *et al.*, 2018). These rapid onset and intensification of drought conditions with severe impacts occur when extreme weather anomalies persist over the same region for several weeks or months (Otkin *et al.*, 2018). Although drought is a natural hazard, it is partially socially constructed and can be triggered or exacerbated by human activities. These hazards can systematically alter human, plant, and animal habitats to create conditions that allow for the spillover of pathogens from natural zoonotic hosts to humans. In this altered environment, the pathogen may seek other habitats (foraging behavior) and can sometimes interface with humans resulting in zoonotic spillover (transmission of a pathogen from animal to humans) or through vector-based transmission (such as malaria) (Jaakola *et al.*, 2014; Alexander *et al.*, 2015).

COVID-19 was first detected in Wuhan city Hubei Province in China in late December 2019. The Province suffered the worst drought in nearly 40 years. Precipitation decreased by 50 to 90 percent in 2019 compared to the same period in the previous years (Sun *et al.*, 2020). Historically, drought has preceded (in some cases concurrent) other pandemics and epidemics. Pinzon *et al.* (2004) examined eight Ebola outbreaks from 1994 to 2002 and found an association with drier-than-normal conditions, characterizing drought at the end of the rainy season for a majority of the outbreaks. Xiao *et al.* (2012) analyzed the environmental characteristics (including climate variables) preceding the emergence of the H1N1 virus in Changsha province in Yunnan, China. Their analysis showed that the outbreak of H1N1 in Changsha significantly correlated with meteorological conditions characterizing drought. SARS, the first known zoonotic introduction of coronavirus into the human population in November 2002 from Guangdong Province in eastern China witnessed a significant drought during 2002. The drought was the result of almost zero annual rainfall, which dried up more than 1 300 reservoirs and affected about 286 000 hectares of farmland (Sun *et al.*, 2020). The 1990s emergence of Nipah virus outbreak in South and Southeast Asia is a clear example of the amplification of agricultural encroachment via drought (establishment of monoculture plantations and proximity of animal husbandry to wild habitats) (Hasebe *et al.*, 2012; Deka and Morshed, 2018). Rieckmann *et al.*, (2018) estimated the risk of cholera outbreaks during periodic droughts and floods compared with drought- and flood-free periods in 40 sub-Saharan African countries from 1990 to 2010. They reported that cholera outbreaks were registered in one of every three droughts and one of every 15 floods. The cocoliztli epidemic (or the great pestilence) is another example where drought precedes the epidemic (Acuna-Soto *et al.*, 2002).

Drought and famine are closely associated with pandemics in Africa. Famine following a serious drought helped propel cholera outbreaks in 1835 and 1893 in Ethiopia. Similar events were witnessed in Tunisia (1865-1866), Madlebe area of the Thungulu region of KwaZulu-Natal, South Africa (1982-1983), and Southern Africa (1992). Investigations into the conditions that contributed to the spread of the virus suggested that drought may have played a role (Munoz *et al.*, 2016). West Nile Virus, a disease transmitted by mosquitoes, has also demonstrated a positive relationship with drought conditions (Epstein and Defilippo, 2001; Shaman *et al.*, 2005; Johnson and Sukhdeo, 2013).

Contemporary policies and practices view drought through human-centric lens and do not fully address the ecological dimensions of drought resulting in loss from diseases, other than ecosystem services (such as provision of water for irrigation and drinking, restoration of vegetation and water bodies) (Redmond, 2002; Crausbay *et al.*, 2017). Pandemics like COVID-19 and other infectious diseases emerge due to disturbance of the intricate interactions of human-ecology-ecosystems. The impact of drought on the human-ecology-ecosystem interactions are both direct and indirect, spatially diffuse and has multiple `downstream´ effects causing serious hydrological imbalance and affecting the natural climate cycle (Table 1). Some of the drought impacts can directly trigger epidemics and pandemics. These include inadequate availability of water and poor water quality, movement of population from rural to urban areas, mono-cropping that affects the biodiversity and pollination driving nutritional insecurity and encouraging human-animal interface. These mechanisms by which drought triggers infectious diseases could be the focus for investing on post-COVID-19 response strategies and towards building-back better a drought resilient society and their sustainable ecosystems. Besides managing drought, it is also important to investigate cross-sectoral approaches to managing and reducing risks of zoonotic or other infectious diseases. One Health that recognizes the interconnectedness of human, animal and ecosystem health (Lebov *et al.*, 2017) and the aligned initiatives of EcoHealth and Planetary Health offer inter-disciplinary and, cross-sectoral frameworks that could be leveraged to better understand the links between drought, ecosystem health and zoonotic diseases.

Table 1. Schematic representation of links between drought and diseases

Component	System/ services	Characterization during drought	Factors triggering disease outcomes	Broad types of pathogens affected & the diseases
Ecosystems services	Water (Stanke *et al.*, 2013)	Affects the quantity and quality of water that can be detrimental to aquatic life and drinking water, impacting food production, industries, livestock farming, fishing, and subsistence farming	Inadequacy in the availability of quality and quantity of water, overlap of humans, animals and vector habitats in remaining water sources amplifying infection	Virus, bacteria, parasite Water-, food- and vector-borne diseases
	Land degradation (FAO, 2017)	Soil erosion, loss of biodiversity, reduced food production, salinity in soil, flash floods, frequent dust storms	Loss of vegetation cover/bare land – leading to soil erosion, poor air quality/ pollution; loss of livelihoods (due to loss of biological and economic productivity of land)	Virus, fungi Skin and eye diseases, (chronic) respiratory infection, cardiovascular diseases, suicides
	Food and nutrition (Stanke *et al.*, 2013)	Shortage and contamination of food, increase in food prices, non-transportation of food items, inadequate storage resulting in wastage of food	Lack of nutritious-based food, and inadequate incentives for drought-tolerant crops	Virus, bacteria, parasites Malnutrition and dehydration, water, food and vector-borne diseases, zoonotic diseases
	Air quality (Stanke *et al.*, 2013)	Low humidity, heat waves and dust storms	heat and dust are conducive for infectious respiratory diseases	Cardiovascular and cardiopulmonary disease, respiratory diseases, fungal infections (rashes), acute respiratory infection

Human environment	Highly dense settlements (Raja *et al.*, 2020)	Formation of heat islands, proximity conducive for spread of diseases	Increase in transmission of climate-sensitive diseases	Virus, bacteria Tuberculosis, respiratory diseases, heat strokes
	Built environment (ULI, 2013)	Poor housing, inadequate ventilation, poor quality structures, inadequate planning	**Conducive for disease transmission** nce syste	Virus, bacteria, fungi **Acute respiratory infections and mental health diseases**
	Sanitation and hygiene (Stanke *et al.*, 2013)	Water scarcity affects its availability for cleaning, sanitation, hygiene and drinking water, poor solid waste management	**Inadequate availability of water for drinking and sanitation for hygiene and food**	**Diarrhea, skin infections and vector-borne diseases**
	Human behavior (Chua, 2010)	Close interaction with animals and wild animals, unhygienic eating habits, poor maintenance of livestock	**Encroachment of forest land, poor human dietary habits, and increasing human-animal interface**	Virus, bacteria **Zoonotic diseases**
	Financial market (Laborde *et al.*, 2020)	Adverse effect on financial market resulting in job loss, reduced income, and impact on food-value chain	**Inadequate regulation of food-value chain during pandemic**	**Stress, anxiety, suicide, depression, and aggressive behavior**
	Migration (Kluge *et al.*, 2020)	Pastoral movement, globalization, rural-urban migration, and everyday migration	**Failure to track and contain the infections, globalization, and rural-urban movement of people, pastoral communities**	**Faster reproduction rates, challenges in tracking infected individuals, unequal health services affect the treatment process**
	Food and dietary habits (Development Initiatives, 2020)	Inadequate dietary habits, consumption of non-local foods, food insecurity, mono-cropping, inadequate understanding of immunity-based food	Inadequate awareness on nutritious immunity-based food	Malnutrition and dietary-related diseases
	Inadequate governance (Sena, 2019)	Inadequate early-warning system, inadequate policies to manage drought, inadequate policies to govern uncertainties	Ignorance on the role of ecology on human health leading to poor early warning and resilience measures	Inadequacy to take pro-active strategies for drought risk reduction

Ecology	Plant (da Silva *et al.*, 2013)	Reduction in growth processes, drought-stressed plants are attractive or acceptable for plant-eating insects	Reduction in vegetation results in shifting of habitats	Virus, bacteria Insects and wild habitat, feeding on diseased or poor vegetation, search for new habitat
	Forest (da Silva *et al.*, 2013)	Mortality and morbidity of plant/tree species, loss of animals/insects, heat wave, wildfire, movement of forest animals and insects	Current interventions in forest conservation have been on vegetation, with poor understanding of the biodiversity	Virus, bacteria Opportunity of zoonotic spillover, and infectious diseases
	Insects (Mattson and Haack, 1987)	Favorable for growth of phytophagous insects, enhances insect detoxication systems and immunocompetence, genetic changes in the insects during drought	Understanding the behavior of insects and its genetic changes	Virus, bacteria Vulnerable for pathogens to spillover to other habitats

Interaction between COVID-19 measures and other stressors on drought vulnerable communities

The COVID-19 has tested our governance systems, which are already stressed by climate change, economic slowdown, and growing inequality. The measures taken to address COVID-19 impacts have had significant impact on drought vulnerable communities in several ways.

a) *Migration and migrant workers*: One of the impact of lockdowns during COVID-19 is restriction in the movement of migrant workers (rural-rural and urban-rural), as they seek to return home (mainly in rural regions). These workers, who are already vulnerable to droughts and related disasters are often ignored during the pandemics given their involvement in the informal sector. Civil society organizations have been providing accommodations, food, and other basic needs, and national and regional governments have been providing aide in the form of financial compensation, free food rationing and clothing,

and protecting tenancy in cities. In addition, the migrant communities, especially women and children, need information and counselling on the pandemics, job search, promoting digital literacy, ensuring adequate basic services and environmental hygiene. It is important to reconsider inclusion of pandemic in transboundary movement protocol to monitor and secure the health of migrant workers and communities to avoid spreading of disease

b) *Agricultural recovery and sustenance*: Agriculture suffers the most as COVID-19 significantly curtails the entire chain of food production and consumption including the loss of jobs, access to markets and associated competition for resources often resulting in conflicts (OECD, 2020b).

   i. As mentioned above, limits to mobility of people across borders and lockdowns are contributing to labor shortages for agricultural sectors in many countries, particularly those characterized by periods of peak seasonal labor demand or labor-intensive production (OECD, 2020b). On the other hand, disruptions in the sale of agricultural produce from the farmers' gate are in some cases causing surpluses to accumulate, putting a strain on storage facilities and, for highly perishables, increasing food losses. In combination, these effects are putting a strain on farm incomes. Moreover, those farm household income losses may be compounded by reduced off-farm income, particularly in developing countries.

   ii. The impacts of COVID-19 are immediate and appalling for smallholder farming families. These small-holders not only face problems in accessing food for their survival and adequate nutrition due to COVID-19, but also the biggest disruption in collecting and transporting agriculture produce to areas of consumption (FAO, 2020). This strain might increase the rates of suicide. Strengthening the resilience of these communities through subsidies, insurances, food distribution, grants, and loans is critical to guaranteeing their food and nutrition security.

   iii. Financial recovery stimulus package that covers financial incentives for farmers – such as employment in non-farm activities, loans, and grants– can offer significant buffer for the farming communities. Insurance policies designed to release discretionary funds for farmers will be an added value. Several countries have initiated such measures providing security to the farming communities.

c) *Global and local trade*: One of the biggest hurdles during COVID-19 has been in the disruption of goods and services safely to consumers (OECD, 2020b). Ensuring and protecting the function of the food-value chain; promoting the production (and availability) of diversified, safe, and nutritious food; promoting `more crop per drop´ technologies; introducing drought-resilient crop

varieties; and promoting sustainable cattle farming against drought impact can strengthen the resilience of farming communities against drought. Road blocks and checks in China during COVID-19 prevented smallholder producers to sell or buy products, resulting in a loss of income and it has potentially affected future cultivation seasons (FAO, 2020). A similar impact could be expected in many parts of the Latin American, African, and Asian region.

d) *Urban-rural interface*: COVID-19 has resulted in "multilocality", which means that individuals may live across multiple locations, which many of the rural-urban policies are yet to catch up (Goodwin-Hawkins *et al.,* 2020). Multilocality, for instance, strongly influences the taxes and services operating in an area. Typically, authorities tax based on the residents. In a multilocality context, taxing has to be based on primary residence. This raises the question for fair allocation of funds across regions. Multilocal people may not be well captured by health systems, so they may not be covered by health system interventions against pandemics, such as vaccination and awareness raising. Multilocality can take many forms, from seasonal migration to holiday homes, weekend commuters, to transnational workers, labor market flexibility and digital connectivity. Such multilocality blurs the urban-rural interface. With more affluent urban residents planning to take advantage of remote working capabilities being promoted by companies (which might lead them to move to smaller towns and countryside settlements), the productivity of quality land might be hampered. This affects the allocation of funds (namely to rural areas), environmental quality, taxation policies, and services. This will have significant change in land characteristics and price, which requires monitoring to avoid animal and human interface in future pandemics.

e) *COVID-19 and the unequal immune systems*: Impacts of COVID-19 have been unequal partly due to malnutrition and food insecurity. Undernourished people with weaker immune systems are at greater risk of severe illness due to the virus (Development Initiatives, 2020). People having poor metabolic health and old age are strongly linked to worse COVID-19 outcomes. This is compounded with people suffering from socially-embedded inequities – including the poor, women, and children, those living in fragile and conflict-affected regions, minorities, refugees and the unsheltered. Though boosting immunity through vaccination is a response to pandemic threats, nutritional resilience is the key element of a society`s readiness to combat the threat.

Post COVID-19: what investments are needed?

COVID-19 brings a heavy toll on individuals, communities, governments and the private sector. The virus has not only claimed millions of lives but has also resulted in severe economic burden. Measures to contain the virus and to mitigate impacts also resulted in strain on national budgets and affected people's ability to care for and nourish themselves and their families . Drought response in the aftermath of the COVID-19 pandemic should thus include investments in the following:

a) *Communication and partnership*: Promoting partnership (locally and regionally) and public outreach to leverage existing drought management programs and infrastructure in a coordinated effort can enhance the community's resilience to drought. In addition, leveraging on local networks in the dissemination of credible and timely information, access to agricultural inputs, provision of basic commodities for everyday living, integrating public health into planning, and non-farm financial incentives play a vital role in bolstering adaptive capacity of the farming communities.

b) *Pastoral recovery*: Pandemics undermine the pastoralists` drought coping mechanisms, namely: their mobility, social networks, livestock markets, managing scarce resources and their ability to deal with livelihood insecurity. Providing reliable livestock market outlets, strengthening protocols to monitor public health emergencies during transboundary livestock movement, strengthening contingency funds, and learning from locally embedded response mechanisms of pastoralists, learnt through living with uncertainty, can sustain the pastoral economy.

c) *Agricultural resilience.*

i. Conserving water in its full capacity in terms of quality and quantity (such as recycling, reuse and rainwater harvesting, choice of less water-intensive and drought resilient crops, and water management technologies),

ii. Developing financial instruments (pricing, grants and subsidies, insurances, guarantees, blended finance, etc.) can enhance sustainable use of resources for agricultural produce. The WASAG Finance Working Group (Zimmer *et al*., 2021) highlights three essential pillars as crucial for financial sustainability: (i) to generate and capture value through increased production, provision of ecosystem services, provision of societal values and through reclamation of degraded land; (ii) implement a holistic de-risking approach to involve all stakeholders in developing financial instruments, contractual mechanisms and resilient practices and (iii) creating financial support mechanisms by building trust to attract funding.

iii. Developing green jobs in ecological-friendly industries and non-farm activities (UNCCD, 2018).

iv. Enhancing food security through ensuring the supply of basic food items (public distribution system) at optimal prices for the poor and vulnerable (such as smallholder farming families).

v. Livestock farming and its industry pose risks of zoonotic spillover. To ensure and avoid zoonotic diseases, we need to understand risks from overlapping resource use by humans, livestock, and wild animals, and how these alter under drought conditions in order to design appropriate interventions such as exclusion zones, vaccination, and vector control.

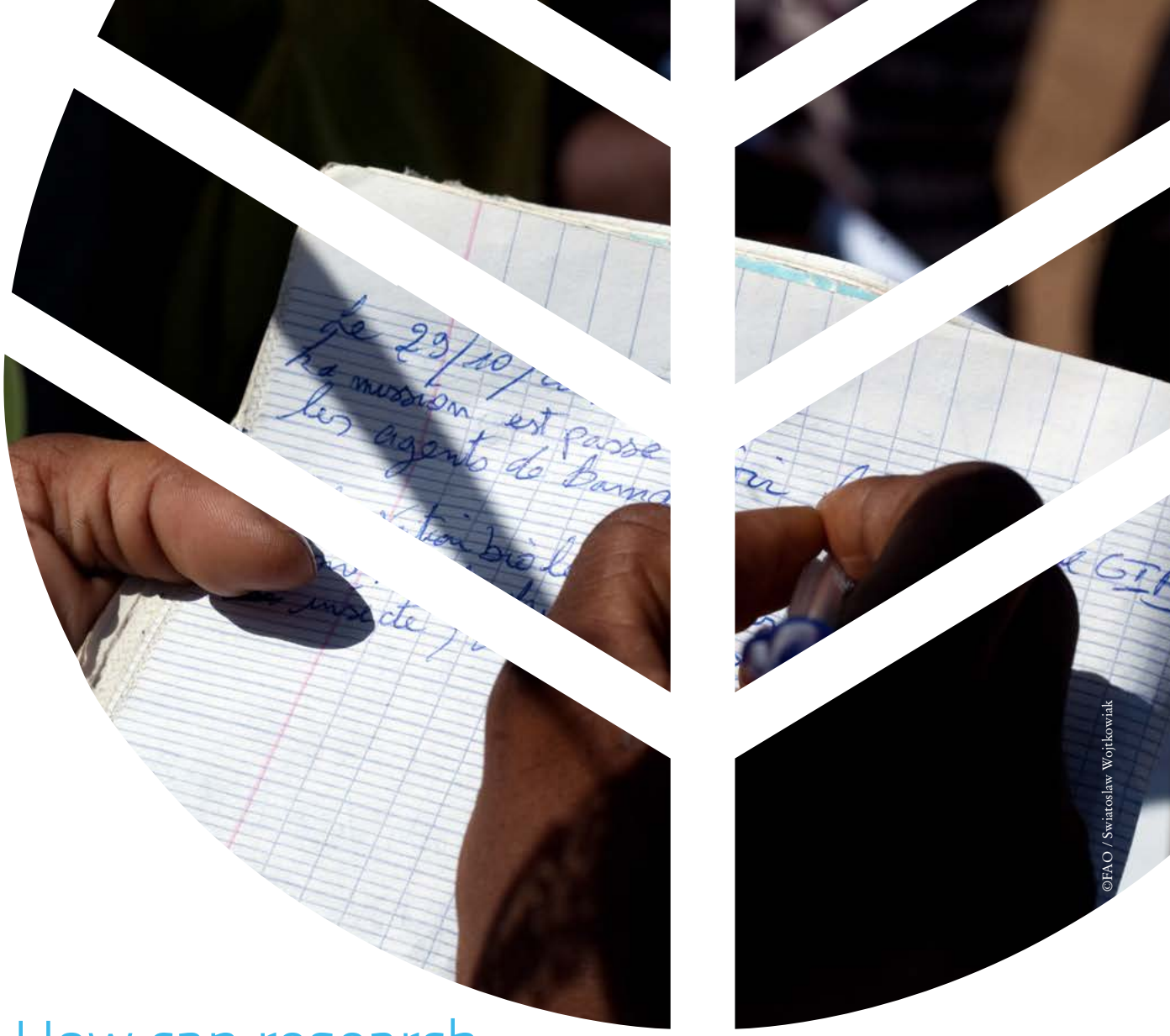
vi. Practicing sustainable dryland agriculture will further enhance all the above, including (but not limited to) agroforestry, intercropping systems, diversified intercropping systems, maximizing economic water

productivity, agroforestry, and integrated crop-livestock-forage systems. The WASAG working groups will pursue opportunities to foster the sustainable dryland agriculture spanning global, regional and country levels across river basins, local and community levels with appropriate actions at all scales for the next four years (2021-2024) (FAO, 2021).

vii. Practicing nutrition sensitive agriculture aimed at achieving balanced diets and boosting the immune system and metabolic health should be an essential component of agricultural resilience in order to increase the capacity of the most vulnerable in communities to cope with pandemics.

d) *Strengthening global-local food-value chain*: The global food-value chain is being disrupted, while local food systems are struggling to meet the market requirements in both developed and developing countries, revealing the fragility of the `global´ systems during pandemics. It is important to have response strategies (World Bank, 2020) that (i) treat food as an `essential service` to keep food moving and opening special procedures (`green channels´) for food, trade, and agricultural inputs to ensure supply chains are open and functional; (ii) incorporate necessary health and safety measures along the food supply chain; (iii) engage government to boost local production with inclusion of adaptive technologies and measures, and (iv) support the most vulnerable population with various safety net programs.

Drought response post-COVID19 must take into account pandemics and disaster-like situations in building a resilient society. Integrating public health into drought management strategies can help bolster adaptive capacity of the farming communities, especially the pastoral communities. These supported with innovative technologies and financial instruments can boost their income and create green jobs. Strengthening global-local food value chain through green channels and safety measures can enhance adequate returns to the farming communities despite threats from pandemics. Increased attention to understand risk from overlapping resource use by humans, livestock and wild animals can help in developing appropriate public health interventions and drought response strategies to reduce zoonotic spillovers. Promoting localized agricultural produce and diversified intercropping with global outlook can enhance nutrition-sensitive agriculture and boost immunity.



How can research help improving the results from investing in more drought-smart resilient societies?

It is important to focus on the underlying causes behind pandemics and epidemics, and drought, amongst other climatic and non-climatic environmental changes, could fundamentally influence future infectious disease outbreaks. This focus could overwhelm the adaptive capacity of humans, their ecosystem, and the ecology among vulnerable systems. Investments in social, financial, ecological, and institutional systems are required towards building resilience of human societies to drought to prevent future disease outbreaks.

a. *Research on drought pathways to pandemics*: Longitudinal studies are needed to understand the droughts-plants-animals-human interface (Stanke *et al.*, 2013). Promoting inter-disciplinary research can boost our understanding

of both the social and political processes, as well as the ecological and environmental processes precipitating zoonotic spillover. This is supported with collaboration with international agencies, such as the Food and Agriculture Organization of the United Nations, World Meteorological Organization, World Health Organization and UNCCD might pave the way for a greater insight for practical solutions.

b. *Strengthening e-learning infrastructure*: Strengthening e-learning infrastructure tailored for marginalized rural areas (e.g. farming and pastoral communities) provides an opportunity to sensitize people on the access to healthcare, medicine, water and sanitation, protecting the agricultural value chains, and promote education and awareness campaigns. The Global Farmer Field Schools[2] initiated by FAO offers guidelines and precaution measures to minimize the spread of the diseases and facilitates digital solutions to farming communities. E-learning also plays an important role to facilitate education. It is a long-term investment for pastoral/farming households with the view that it offers opportunity for employment and therefore a source of alternative income (remittance) to rely on by households of employed persons, especially during droughts. However, lack of online teaching skills among educators, time-consuming preparation of lesson plans, inadequate technical support, inadequate learning environment at many rural homes, and traffic overload in online education platforms have been some of the major challenges (Soni, 2020).

c. *Drought monitoring and early warning systems:* Mapping the vulnerable ecology and ecosystems are important for implementing integrated land and water management to balance demand and services, food demand and production, to optimize ecosystem conservation, and rehabilitation. Mainstreaming this early warning system with integrated climate risk management can help to focus on mitigation, preparedness, response, and adaptation. Mapping of vulnerable communities to protect and make the smallholder farming families resilient through community-based agri-business opportunities, diversification of their income strategies, and innovating financial support can enhance their capacity.

d. *Immunity-based food security*: Promoting herbal-based or nutritional and wellness related food produce can improve immunity among humans through diversification of crops, promoting urban farming, diverse rainfed crops, drought-tolerant crops, such as families of millets and legumes that thrive under harsh environmental condition and are good sources of high-quality protein and micronutrients. A context-specific approach to agriculture produce that strengthen diets and healthy living are often under-researched and do not attract much attention from national and international agencies due to its localized production and invisibility in market.

[2] http://www.fao.org/farmer-field-schools/ffs-overview/covid-19/en/

e. *Adoption of national food-based dietary guidelines* (FBDGs) can provide context specific recommendations for agriculture produce and advice on healthy diets and lifestyles (Springmann *et al.,* 2020). Adoption of these was associated with reductions in premature mortality of 15 percent on average and mixed changes in environmental resource demand, including a reduction in greenhouse gas emissions of 13 percent on average (Springmann *et al.,* 2020). Promoting diversity in rainfed crops, improved pricing policies, protecting the quality of produce in the value-chain, diversity in crops per plot making it resilient to pest, and insects, integration of more local produce, and promoting integrated food policy can make the food systems resilient to the effects of drought.

f. *Drought-resilient ecosystems:* Taking adequate actions to protect human health and the environment (maintaining the adequate supply of water, rainwater harvesting, recycling, and reuse of waste management) and adapt to future changes in weather and climate patterns that can reduce resource scarcity. Enhancing integrated land and water management planning in both urban and rural areas become urgent to balance water use for human population and livestock, and for ecological use. Tailoring land-use practices as per the diverse land tenure arrangements and regulations are important in reducing the animal-human interface. Drought-smart farming can ensure transformation from high water demanding crops and varieties to drought tolerant species and animal breeding for stability of food production systems with protecting the ecology.

g. *Securing land tenure security*: Insecure land tenure arrangements will have significant impact following pandemics with land-use changes, fragmentation of landholdings, forest encroachment and infringement of urbanization. Ensuring adequate solid and wastewater management to protect environmental hygiene, environmental cleanliness, food regulation, safe housing, improved water supply (quality and quantity), environmental cleanliness, effective liquid, and solid waste management and food regulation will enhance the resilience of urban utilities, services agencies, and farming communities.

h. *Enhancing community-based resilience*: Communities in drought-prone areas have extensive knowledge of ecological conservation and employ strategies to conserve water (such as rain-water harvesting, moisture retention, choice of rainfed crops, etc.), land quality (tillage practices and application of inputs) and agricultural processes. Promoting non-farm income-generation opportunities, diverse insurance schemes, subsidies, and non-farm employment can strengthen the resilience of communities against drought.

i. *Ecological resilience*: Identify areas of drought `refugia´ (the areas where animals and plants can survive through a period of extreme drought events) for preservation and expansion of the resilience capacity of the ecology and the ecosystems to reduce the impact of drought extremities. This can promote heterogeneity in the ecosystem-based adaptation with triple line benefits from

payment of ecosystem schemes and sustainable land management, income and revenue, and environmental protection (Krawchuk *et al.*, 2020). Monitoring the vulnerable hotspots of the ecology (areas of forest loss, assessing the foraging behavior of animals,contact rates between people, livestock, wild animals and between the above, disease vectors) and ecosystems (encroachment on forest, changes in land-use practices, urban expansion, tourism, the behavior of insects -namely bees, and domestication of animals) might strengthen actions to avoid zoonotic spillovers, which will enhance resilience strategies for decision-makers.

j. *Application of modern technology:* The role of artificial intelligence and of mobile and remote sensing technology could be explored for practical ways to ensure efficiency (e.g. crops get only as much water as they need at the different stages of growth) to enhance early warning systems that go beyond meteorology and forecasts. The experience from the COVID-19 lockdown has realized the significance of communication technology, which can immensely advance early warning and response measures if harnessed to facilitate reporting, virtual learning, trading and tracking spatially and temporally the changes in the ecology, ecosystem services and humans.

k. *Integrating public health into decision-making*: often drought planning, and preparedness activities do not incorporate public health. As drought plays a significant role on human health, it is important to include representatives from Public Health, environment and Animal health ministries and departments into drought planning activities. Due to the complexity of health outcomes from drought and the potential for spillover events, a `One-Health` approach will allow individuals with diverse expertise (e.g. public health, animal health, plant health) to provide feedback on possible outcomes from drought and its interactions with stressors from infectious diseases.

Conclusion

This paper has demonstrated that the interactions connecting humans, their ecosystems and the ecology can be destabilized by shocks such as drought. Unexpected outbreaks and break-downs can follow the (more predictable) drought shock. This means that additional consideration and provisions for the overall health and well-being of vulnerable communities and their ecosystems is likely to be needed following droughts. However, for this to be effective, it would ideally need to be put in place before the drought hits. In light of this, more attention to human and ecosystem health should be factored into drought preparedness, resilience, and recovery.

Increased investments are needed from government and international agencies - not only in responding to the post COVID-19 recovery, but also to build the drought-resilience of societies and their ecosystems for the future. There is an important role for inter-disciplinary research to play in guiding the necessary innovations and cooperation. We still have much to learn about how best to prepare for drought, including the underlying threats that they raise for human and ecosystem health. Understanding and managing these will be essential to prevent future disease outbreaks and achieve healthy living conditions for all.

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