International Water
Management Institute

IWMI is a CGIAR
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Submission to the First Global Stocktake

Contents

Key messages

- By enhancing water, food, and energy security, water-related increases in adaptive capacity reduce the vulnerability (and increase the resilience) of people and societies. Water resource–centered adaptation must become a core element of all future human socio-economic development.

- To be effective climate resilient water management (CRWM) requires integrated, forward-thinking policies that are not only adaptable to changing climatic conditions, but also seek to maximize economic and social welfare in an equitable manner while ensuring the continued health of ecosystems. CRWM should enable not only responses to climate impacts – building resilience in human populations and both built and natural environments - but also enable us to choose the future we wish to live in.

- The most significant challenge today is gathering, synergizing, and organizing effective insights for implementation whilst simultaneously mobilizing change at the scale and speed required for successful adaptation across diverse contexts.

- The interrelationships between adaptation and mitigation need to be carefully considered and an appropriate balance struck.

- Many of the challenges that farmers and rural vulnerable communities face to adapt to climate change – particularly in developing countries - relate to capturing, storing and accessing uncertain rainfall, managing water resources, recovering from floods and droughts, enhancing soil moisture retention and improving water-use efficiency.

- New data and tools for risk management — as well as rapidly scalable and inclusive innovation — are critical. New knowledge is needed to underpin inclusive water management as uncertainties and climate shocks expand over the 21st century.

Context

Water security is deeply intertwined with climate security both of which are key to our collective future, yet many parts of the world today remain deeply water-insecure. To meet the United Nations Sustainable Development Goal (SDG) 6 and successfully implement the Paris Agreement, there is an urgent need to accelerate our efforts to ensure a water secure world – this is especially important given rapidly expanding existing threats to water security for communities, countries, and basins. As the Intergovernmental Panel on Climate Change (IPCC) recently reported, water risks are intensifying around the world as climate change tightens its grip and shocks the planet's hydrological systems. What we know is coming are more droughts, floods, and extreme rainfall, more variable and less reliable rainfall patterns generally and especially with tropical monsoons, melting glaciers, and sea-level rise. All affect the reliability of access to the water we use for our basic functions, the food we eat, the energy we use, and for industrial and commercial processes.

Traditionally, natural resources have typically been managed in 'sectoral silos' with little consideration for other related sectors. In recent years, emphasis has been given to integrated and holistic approaches to the governance of natural resources. The synergies and trade-offs among the sectors can then be better identified and addressed using concepts like water, energy, food, and ecosystem nexus to maximize benefits and minimize risks[1]. In this new era of water risk, governments, businesses, and water users across sectors — as well as the global water science community — need to do more to adapt and build water security for the 21st century for the benefit of future generations. Without immediate and bold action, water security is set to worsen.

Water's importance to achieving sustainable development, building climate resilience, and strengthening livelihood opportunities compels the international community to urgently prioritize the sustainable management of water. However, poor water governance, underfunded water services and infrastructure, a fragmented science community and evidence base, and the slow pace of change and innovation in water management combine to make achieving water security an elusive goal in many countries. Climate change impacts on water resources just further exacerbates these challenges.

To meet this current and emerging threat the global water community will need to work hard to build partnerships and coalitions among the policy, business, development, practitioner, and science communities, balancing voices from the Global South and Global North in order to focus and strengthen the science base for action on water security. Collectively we need to ensure that political progress towards a more urgent and coherent agenda for water policies, investments, strategies, and accelerated action is better supported by scientific progress. Doing so will enhance our collective ability to deliver and catalyze high-ambition, future- ready innovation and inclusive, science-based solutions for water security.

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[1] One such example of this thinking being put into practice is the CGIAR initiative 'NEXUS Gains: Realizing Multiple Benefits Across Water, Energy, Food and Ecosystems ' which aims to realize gains across water, energy, food and ecosystems. https://www.cgiar.org/initiative/28-nexus-gains-realizing-multiple-benefits-across-water-energy-food-forest-biodiversity-systems/

Connecting Water Systems Science to Water Security Priorities for accelerated action on SDG 6 and increased climate change ambition under SDG 13 must address multiple drivers of change — including soaring water demand for food production, energy generation, and economic development, among other uses — while prioritizing marginalized communities, vulnerable people, youth, and equality between women and men.

In a rapidly changing climate for which the past is no longer a reliable guide for planning for future water risks, new data and tools for risk management — as well as rapidly scalable and inclusive innovation — are critical. New knowledge is needed to underpin inclusive water management as uncertainties and climate shocks expand over the 21st century.

Part I: Adaptation

Climate resilient water management

Water is the principal medium through which the combined societal stresses of climate change will be manifested. The direct impacts of climate change on water – changes in precipitation, river flows and natural storage, as well as increased intensification and frequency of floods and droughts - will be effectively "multiplied" via effects on many interlinked sectors in the water-energy-food-environment-livelihood nexus. Hence, climate change exposes human populations to multiple enhanced (direct and indirect) water-related risks, including livelihood and health risks.

What is currently less well understood is that climate resilient water management (CRWM) may be the most effective single strategic intervention to cope with and even avoid negative climate impacts: adaptation to climate change is primarily about better water management (UN Water, 2010). Options for improved water management, from farm level (e.g., irrigation) to basin level (e.g., better integrated resource management), provide the opportunity to not only reduce current water-related risks but also mitigate many of the potential negative impacts of climate change. **By enhancing water, food, and energy security, water-related increases in adaptive capacity reduce the vulnerability (and increase the resilience) of people and societies** (Figure 1). **Water resource–centered adaptation must become a core element of all future human socio-economic development.**

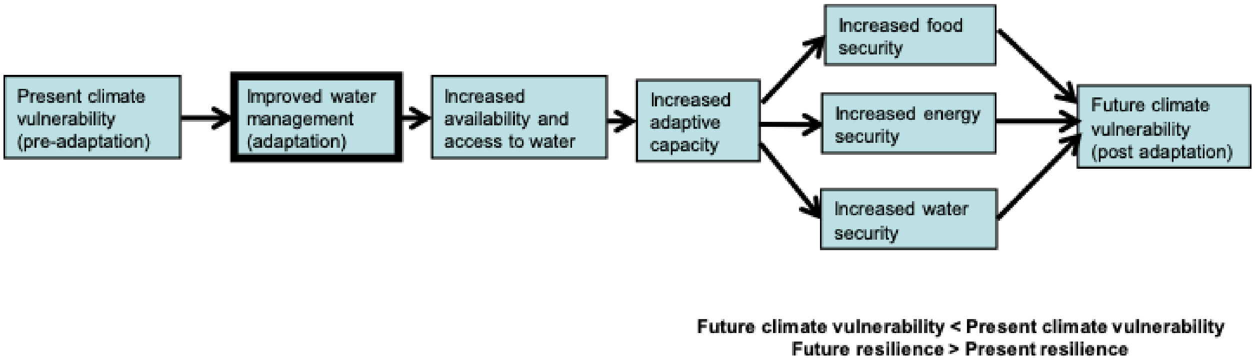

Figure 1: Improved water management: an adaptation strategy to reduce current and future climate vulnerability

Successful climate change adaptation necessitates fundamental changes in all aspects of how water is managed across sectors, political jurisdictions, and multiple scales. Decision-making related to planning and investing in options for developing, allocating, distributing, and governing water resources has to change. In some places, large changes to regional hydrological processes will necessitate transformational changes in the management of water resources. For example, in places like California, and some of the rivers flowing from the Himalayas, a shift from summer flows, significantly supplemented by snowmelt, to rain-dominated systems will alter many qualities that ultimately affect short and long-term water availability. Although the magnitude of change will not be as great everywhere, success in navigating these changes, large and small, in different social groups and across sectors and scales, will largely determine future adaptive capacity.

To be effective CWRM requires integrated, forward-thinking policies that are not only adaptable to changing climatic conditions, but also seek to maximize economic and social welfare in an equitable manner while ensuring the continued health of ecosystems (James et al., 2018). Ideally, CRWM should enable not only responses to climate impacts – building resilience in human populations and both built and natural environments - but also enable us to choose the future we wish to live in.

What are the barriers and challenges?

Deep uncertainty in hydrological processes, water use and future water demand

Water is naturally variable in space and time, which has always challenged water resource planners, decision-makers, and engineers working in a quantitative context and/or on long-lived structures, agreements, and institutions. For at least two centuries, efforts to constrain uncertainty were premised on the assumption of stationarity[2] (Milly et al. 2008). Stationarity is a simplifying assumption - if we are confident about what the future will look like, we can optimize our operations, economic choices regulation and governance, developing "ideal" solutions for one climate. However, climate change introduces trends into hydrological behavior that invalidate this assumption; the past is no longer a reliable precursor of the future and using only past data to guide decisions can lead to perverse and maladaptive results. Indeed, many observers have become concerned about the emergence of "deep uncertainty", where decision-makers are unable to determine the credibility of widely divergent visions of the future. Highly optimized approaches to water management under these conditions may result in "brittle" and inflexible solutions. These conditions are especially concerning if we want to avoid making decisions that may be difficult to undo, modify, or adjust over time.

Recently, widespread applications of climate science to water decision making have simply substituted the output of climate models for statistical analyses of past weather and climate patterns. If these models were associated with sufficient confidence, then they would be able to support most water related decisions. However, climate models may not even describe the limits of the range of possible climate change and are unable to provide probabilistic estimates of the uncertainty (e.g., which scenarios are most likely). Although most General Circulation Models (GCMs) and Regional Climate Models (RCMs) project air temperature changes with reasonable confidence, there is often low confidence in terms of the magnitude and the direction of change in precipitation and flows controlling water availability. Furthermore, GCMs have the least skill in generating the variables that are typically most important for water resources planning and investment, such as hydrological extremes (e.g., floods and droughts) or shifts in seasonality. Hence, current climate change projections alone are not useful for investment planning (Box 1) and water resource planners are generally poorly equipped to evaluate risks and system vulnerabilities (Ray and Brown, 2015). Furthermore, there is little consensus on the current water use across the agricultural, energy and other sectors within basins, which further amplifies the uncertainty and estimations of future projections.

Box 1: Climate modelling - Current limitations

A study by the World Bank's Independent Evaluation Group (IEG) found that "*climate models have been more useful for setting context than for informing investment and policy choices*" (IEG 2012, 61) and "*they often have relatively low value added for many of the applications described*" (IEG 2012, 69). A more recent study concluded that GCM derived scenarios "*tend not to provide the insights needed for water resources system planning*" (Ray and Brown 2015, 12).

Many studies have focused on uncertainty related to climate inputs and resultant hydrology. In comparison, research on climate change impacts on water demand and related adaptation is relatively limited. The studies that have been conducted reveal that: i) in the immediate future (i.e., to 2025) in many places, though not all, non-climatic factors outweigh climate change in terms of impacts on water

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[2] This presumes that hydrological processes fluctuate within an unchanging envelope of variability (i.e., there is no systematic change in either the mean or the variance of time series). System dynamics remain constant, so that, at any given location, the statistical properties of all aspects of the hydrological cycle (e.g., rainfall amounts, seasonal soil moisture fluctuations, streamflow's and flood frequencies) can be estimated from observations. Furthermore, the longer historic records are available, the more confidence can be placed in these estimates.

(Vörösmarty et al., 2000); ii) climate change will increase global water demand, though this will vary widely with geographic location and climatic conditions (Wang et al, 2016). Although water demand in agriculture will most likely be affected more than demands in other sectors—important because it represents the major proportion of water demand in most places—there remains great uncertainty in the local impacts. In fact, the relative influence of climate and non-climate factors is specific to an individual basin and project context, and must be considered on a singular basis. When evaluating the relative importance of climate and non-climatic factors, issues that deserve particular attention are initial conditions (e.g., whether water supplies are already stressed or floods already present a significant risk), recent local climate and demographic trends, and project lifetime, with longer-lived projects likely to experience greater climate-related stress (Ray and Brown, 2015). Furthermore, adaptation in practice may be constrained by both perceived and actual adaptive capacity. Thus, it is important to note that any local adaptation initiatives could be significantly affected by broader social, economic, and policy changes that shape local vulnerabilities (Jones and Boyd, 2011; Bastakoti et al., 2016).

Lack of consensus on what is needed

Currently little consensus exists around how we identify current and projected risks and then develop adaptive strategies. Solutions specific to particular localities and institutions have been developed and implemented, and some critical insights have emerged about what approaches are more or less successful generally or for specific issues. **The most significant challenge now is gathering, synergizing, and organizing effective insights for implementation whilst simultaneously mobilizing change at the scale and speed required for successful adaptation across diverse geographical and social contexts.**

What are the opportunities, good practices, lessons learned?

Since agriculture is the greatest user of water, enhancing agricultural water management is a key requirement of adaptation. Connecting the demands for food and water security have never been more critical. Against a backdrop of enhanced climate risks, and associated agro-ecological and socio-economic threats, preserving and enhancing food security requires higher agricultural productivity and, importantly, lower yield variability. A recent study showed clear interlinkages between food insecurity and water insecurity across 25 countries indicating that people who frequently have a issues in accessing water are three times more likely to be food insecure (Figure 2). Both agriculture and water management are at the top of the adaptation needs of many countries as expressed in their Nationally Determined Contributions (NDC) submissions.

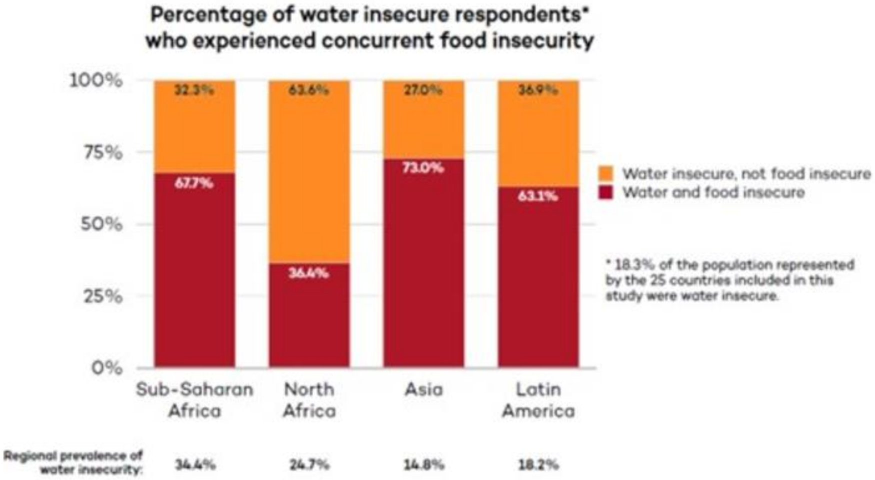

Figure 2: Across regions, a large proportion of people facing water insecurity also reported food insecurity. The overall prevalence of water insecurity ranged from just below 15% in Asia to over 34% in sub-Saharan Africa.

To increase and stabilize output, agricultural production systems must have a greater ability to perform well in the face of, and recover quickly from, disruptive events. More productive and resilient agriculture, so called "climate smart agriculture" requires changes in the management of natural resources.

Different approaches to improve water management can be used to mitigate some of the major impacts of climate change on agricultural production. The most appropriate interventions must be selected carefully to match the specific conditions in any given context, and the extent to which a range of objectives can be met with single interventions is limited. As a result, in most situations, bundles of interventions will be required which are technical, financial, and social in nature. It is important when identifying and designing bundles of water centric innovations to enhance adaptive capacity to distinguish between physical and economic water scarcity people face. In cases of physical water scarcity, emphasis should be paid on enhancing efficiency in the use of resources across scale whilst economic water scarcity requires interventions which enable societies to access those resources. Sustainable expansion of irrigation by addressing economic water scarcity could feed an additional 840 million people whilst avoiding further physical water scarcity (Rosa et al., 2020). Furthermore, increasing yields, necessary for food security and socio-economic development in the short-term, is not always congruent with mitigating climate change impacts, necessary for resilience and sustainability in the long-term. **The interrelationships between adaptation and mitigation need to be carefully considered and an appropriate balance struck. Many of the challenges that farmers face to adapt to climate change – particularly in developing countries - relate to capturing and storing uncertain rainfall, accessing and managing water resources, enhancing soil moisture retention and improving on-farm water management.**

Surface water-based irrigation and drainage

The most obvious, and most common, adaptation to increasingly variable rainfall is irrigation. Today, agricultural policy in many developing countries emphasizes agricultural intensification and irrigation development to meet rising food demand and spur economic growth (Box 2). Irrigation development can be seen as a continuum ranging from large, medium, and small irrigation schemes, often requiring large public investments, to irrigation solutions at a farm, led and invested by farmers themselves.

Box 2: Irrigation in Viet Nam

In Viet Nam rice is cultivated on 82% of the arable land, largely in the deltas of the Red and Mekong rivers, in the north and south of the country respectively. In the 1980s, Viet Nam was a net importer of rice but since the 1990s it has been one of the biggest exporters in the World. Total annual paddy rice production grew from 19.2 million tons in 1990 to 35.8 million tons in 2005. Currently productivity in Viet Nam exceeds 5 $t.ha^{-1}$ and it exports around 3-4 million $t.y^{-1}$ (IRRI, 2013). This turn of fortune was achieved through a shift from self-supporting production to highly intensified cropland systems, supported by significant investment in irrigation infrastructure: at least USD 725 million between 1995 and 2000. Half of Viet Nam's rice production area is irrigated, though competition for water resources is growing rapidly.

Irrigation can, when adequately planned and managed, contribute not only to significant increases in agricultural production, but also to food security, poverty alleviation, rural employment, improved diets and economic development (Domènech 2015; Passarelli et al. 2018). Governments also recognize that under changing climatic conditions, investments in irrigation can represent a pragmatic form of adaptation, particularly in Sub Saharan Africa, where both intra- and interannual variability in rainfall is high (Malabo Montpellier Panel 2018). This reflects demands by households, who often list irrigation as their most preferred, but not implemented, adaptation strategy (Box 3).

Box 3: Irrigation demand in Kenya

Among farmers in a household survey of various agroecological zones in Kenya, almost half (49%) of all farm households interviewed listed irrigation investment as their preferred adaptation strategy (Bryan et al. 2013). This desire was confirmed by focus group discussions, in which irrigation and water harvesting schemes were ranked as the priority adaptations regardless of gender and agro-ecological zone (Bryan et al. 2013).

There is the risk that if not adequately planned, large-scale irrigation infrastructure can increase vulnerability as it fails to cater for sufficient flexibility to climate uncertainty. Furthermore, irrigation systems intended to reduce exposure to risks associated with rainfall variability can, by encouraging the growth of water intensive crops (e.g. rice, cotton and sugarcane) in water-scarce areas, amplify the effects of extreme weather events and, hence, ultimately be maladaptive resulting in negative environmental and social impacts (Lankford 2004; Damania et al. 2017).

In the past, irrigation investment has focused mainly on large formal canal command systems, drawing water from reservoirs, or pumping directly from rivers. However, there are many limitations to irrigation schemes (Box 4) and there is a recognized need that irrigation needs to be more flexible catering to the different farmer needs and contexts of a changing world. Hence, there has been increased interest in identifying suitable irrigation solutions catering to the needs of individual or small farmer groups rather than larger irrigation infrastructure. Farmer-led Irrigation development is conceptualized as '…a process in which farmers, individual and/or group, drive the establishment, improvement, and expansion of irrigated agriculture, often in interaction with other food system actors' (Woodhouse et al., 2016) (Box 5). This provides an opportunity to incorporate aspects of agricultural water stewardship and accompanying regulations and policies to incentivize low carbon and water (re)use pathways of our agri-food systems whilst supporting a more demand led process of climate adaptation.

Box 4: Farmer-led irrigation (FLI) development

Farmer-led irrigation development is a bundle of water centric solutions related to storage, access and (re)use in agricultural production systems translating in bundled solutions tailored to the local context (i.e. natural resources availability, socio-economic, climate) the individual or a small community of smallholder farmers (< 10 ha) are situated (Izzi et al, 2021). Farmers invest or capitalize upon technologies in storage (i.e. water harvesting ponds, small reservoirs, underground storage, managed aquifer recharge), accessing (i.e. manual or motorized electric, diesel, solar photovoltaic pumps, river diversion) and using (i.e. drip, sprinkler, furrow) water for different agricultural value chains including animal and aquatic sourced food as well as water-sanitation and hygiene. Depending on the available water source, farmer-led irrigation development is found next to rivers, small reservoirs, poorly functioning irrigation schemes, shallow and deep wells but also the use of unconventional water sources (i.e. recycle and re-use) is gaining momentum in water scarce areas. Farmers are found to re-invest into irrigation and agriculture by upgrading irrigation technologies (e.g. agrovoltaics, hydrophonics), agricultural inputs and move from staples to high value crops such as vegetables, fruits. Improvements do include for example climate smart agriculture, regenerative agriculture and increased moisture storage, moving from furrow to drip irrigation, moving to precision application, weather, irrigation and agricultural advisory services, reduce drudgery etc. Farmers tend to diversify their cropping systems and the commercial logic of FLI development influences also the investment into improved seeds, fertilizers and strengthen reliability of high value crops (vegetables, fruit) in local markets.

Many of the influences that drove past irrigation development (e.g. population growth, poverty alleviation and economic development) continue to be priorities. However, consideration must also be given to increased water demand from other sectors (e.g. cities, industry and hydropower) and negative effects on ecosystems and biodiversity, including fish, must be avoided or mitigated. **The focus of irrigation needs to shift from simply maximizing crop yields to a much more ambitious approach of maximising net benefits across a range of uses of irrigation water and to do so within a total envelope of net irrigation consumption appropriate to each river basin. This is a much more challenging concept in which multiple objectives need to be considered and the opportunity costs of water need to be explicitly factored into analyses (English et al. 2002), requiring in some cases significant shifts in cropping systems given the changes in climatic conditions and hydrological processes.**

Box 5: Limitations of irrigation schemes

Despite a recognized need for increased irrigation and substantial continued investment in many places, and despite modern technology and advanced scientific understanding, many irrigation schemes suffer from serious problems. Many systems do not operate at the aspirational levels intended in designs (Lankford et al. 2016). Funds for operation and maintenance are often inadequate, leading to breakdowns of pumps, silting of headworks and canals, and non-functioning gates. In many places, schemes are unable to supply water effectively during dry seasons and droughts and, conversely, many are susceptible to damage during floods. Moreover, synergies with other water users, such as municipalities, aquaculture systems or hydropower stations, are seldom developed as irrigation schemes continue to be largely planned and managed in isolation (Lankford 2004; Furlong et al. 2016). Schemes are often designed solely for the irrigation of a single crop (e.g. rice) and there is little flexibility in the timing and volume of water delivery. Although this can be an advantage for operational efficiency, farmers on such systems may have little choice in what crops they grow: an important constraint as both market prices and farmers' socioeconomic aspirations change over time.

Typically, impact assessments of irrigation schemes, when implemented at all, have failed to adequately assess the environmental implications and other, unintended, consequences of irrigation development, which often undermine long-term sustainability and system resilience. In many places, water resources are overexploited and, worldwide, aquatic ecosystems are rapidly degrading (Vorosmarty et al. 2010). Irrigation remains the largest human freshwater withdrawal, at 70% globally and more than 80% in developing countries (Siebert and Doll 2010). A recent study suggests that global water withdrawals for irrigation, estimated at 2409 km^3 year-1 , represent an overexploitation of water needed to sustain riverine ecosystems of 997 km^3 year-1 (Jagermeyr et al. 2017). Furthermore, to fully preserve environmental flows would lead to production declines on more than half the global irrigated croplands and, in the absence of compensating interventions, a total global decline in production of around 5% (Jagermeyr et al. 2017). Thus, we are currently trading off irrigated food production with the preservation of natural ecosystems and the many ecosystem services that they provide, including fisheries (Crossman et al. 2010).

Groundwater

The importance of groundwater is growing, as surface water resources come under increasing pressure and improved and more cost-effective pumping and drilling technologies facilitate access to sub-surface supplies. Globally groundwater use is a key component of adaptation strategies in many areas, and dependence on groundwater as a buffer to climate variability is likely to increase under climate change. Where reliable groundwater supplies are available, the advantages over surface water for irrigation can be very significant. Aquifers provide both storage and transmission of water, and can be developed quickly and incrementally, with low capital cost. In contrast to most large canal systems, water is available directly on-demand, allowing farmers' flexibility and control over timing and quantity of supply.

Conjunctive use of surface and groundwater offers major opportunities for irrigated agriculture and is a realistic adaptation strategy for climate change (GWP 2012). Groundwater development of large alluvial aquifers, closely linked to rivers and replenished annually by the monsoon, can if managed sustainably, potentially replace surface storage (with reduced costs and evaporative losses). Managed aquifer recharge (MAR) a technology applied to capture and store wet season flows, can be used to both mitigate the impacts of flooding and enhance water security by offsetting potential groundwater overuse by enhancing aquifer storage (Box 4). "Informal" conjunctive use also provides opportunities for increasing the overall performance of formal irrigation schemes. For example, in the Dry Zone of Myanmar farmers with plots located in the tail end of some irrigation schemes have invested in shallow tube wells and low-lift diesel pumps to supplement water provided by the scheme. They have resorted to this largely because the scheme fails to deliver sufficient water to their fields. The informal irrigation taps shallow aquifers which are at least partly recharged through canal leakage from the formal scheme (IWMI, 2015).
Groundwater irrigation thus offers opportunities for adaptation to climate change through stabilization of water supply; intensification of production by enabling a dry season crop; and diversification to high value production (Shah 2014). However, two sets of risks must be taken into account before promoting expansion of groundwater use as an adaptation strategy.

First, the largely unregulated nature of groundwater use has already resulted in over-exploitation in many places, and there are concerns over long term sustainability (Taylor et al., 2012). A range of potential responses have been suggested, including: i) demand reduction through crop choice and water saving technologies; ii) supply augmentation through MAR; iii) tradable property rights; iv) community aquifer management; and v) indirect approaches such as energy pricing and rationing (to control pumping) or land use regulation. There are no simple solutions: governance and management practices must be customized for each case, depending on both hydro-geological and socio-economic contexts (Shah, 2014). Second, the potential impacts of climate change on groundwater availability and demand must be considered. For example, changes in precipitation patterns will impact groundwater recharge; and sea-level rise may result in salinization of aquifers in delta areas. The likely impacts are highly uncertain and will be specific to each region and aquifer system. Although the buffering capacity of groundwater to climate change is typically higher than that of surface waters drawn from rivers and ponds, groundwater is not exempt from drought and water table declines can undermine irrigation performance. Good understanding of aquifer characteristics and functions is essential for effective management of groundwater resources. Irrigation is the dominant cause of groundwater depletion, and the impacts of future climate variability may be felt mainly as the indirect effects of increasing irrigation demand (Taylor et al., 2012).

Box 6: Underground taming of floods for irrigation (UTFI)

A novel technological intervention called ‘Underground Taming of Floods for Irrigation’ (UTFI) is being proposed to simultaneously reduce flooding issues in low lying areas and enhance groundwater resources for dry season irrigation (Brindha and Pavelic, 2016). Using principles of conjunctive management of surface and groundwater at the river basin scale, UTFI involves selected harvesting and storage of surplus wet season flows with groundwater recharge structures in upstream areas, to protect urban and other high valued infrastructure downstream; and later recovery of stored groundwater for irrigation.

Analysis of the Chao Phraya River Basin in Thailand indicates that 28% of the wet season discharges into the Gulf of Thailand from the basin could be harvested without significantly impacting on water use from existing surface storage or the riverine and marine ecosystems. Capturing peak flows in wet years requires dedicating around 200 km^2 of land within the basin to groundwater recharge. This would not only reduce the magnitude of flooding, but generate USD 140 million per year in additional agricultural production through irrigation (Pavelic et al. 2012).

Rainwater harvesting

In some areas, access to fresh water resources is limited. Aquifers are too deep or contaminated by salinity or other pollution (e.g. arsenic) and streams may be depleted during the dry season or located too far from where the water is needed. In this situation, small on-farm water storage can be beneficial to deal with the risks of droughts at the onset or during the wet season, or to allow limited irrigation at the beginning of the dry season.

Collecting water from a small catchment area and storing it in village and farm ponds is a common solution in many places. Since they store relatively small volumes of water, most ponds empty every year. They tend to be shallow, with relatively large surface areas, so that, in most cases, a significant proportion of the water is lost through evaporation. Nevertheless, they are useful for livestock watering, domestic purposes and sometimes small-scale irrigation. One major advantage is that they represent a decentralized system that enables individuals and communities to manage their own water for their own purposes. In some instances, small ponds may also be used for aquaculture, though integration of fish and irrigation requirements may not be easy. In some regions of Ghana, Burkina Faso, Ethiopia the Philippines, Indonesia, Northeast Thailand, and the Myanmar Dry Zone, considerable numbers of rainwater harvesting ponds have been established.

Another form of water harvesting that is increasingly popular is roof-top rainwater harvesting. Such structures are primarily used for domestic needs but can also be used to irrigate small vegetable gardens, typically for household consumption. Ideally, storage capacity should be large enough to cover irrigation demand for two to three weeks (Box 7).

Box 7: Rooftop rainwater harvesting and storage in jars in Northeast Thailand

Harvesting of water from rooftops for domestic use is probably more widespread in Thailand than in any other country in the world. With an average annual rainfall of 1,000-2,000mm, harvesting rainwater for domestic use is economically viable provided the right technologies are adopted. A construction boom for rainwater jars followed the announcement of a nationwide rainwater jar construction programme by the Ministry of Interior in 1985. The government, working jointly with local NGOs, supported the manufacture of several million jars. Although it was envisioned that householders would construct their own jars, the small-scale private sector became very active in construction. At the peak of the programme, small village-based manufacturing companies were turning out around 30 jars per day (University of Warwick, 2002). The immense success of the jar programme arose from the fact that the technology met a real need, was affordable, and invited community participation. The programme involved a broad range of stakeholders, including households, communities, NGOs, universities and the private sector (Wang Miles, 2013).

Ecosystem Based Adaptation

Building resilience is not just about increasing yields and productivity. For many poor farmers the ecosystem services of farming systems provide vital livelihood and welfare benefits. Hence, the ability of people to adapt to climate change is inextricably linked to the condition of ecosystems. Healthy, well-functioning ecosystems enhance natural resilience to the adverse impacts of climate change and reduce the vulnerability of people. “Ecosystem-based Adaptation” (EbA), is promoted as an approach that uses biodiversity and ecosystem services as part of an overall adaptation strategy to help people and communities adapt to the negative effects of climate change.

In some places, in Asia, traditional governance systems have enabled rice fields to be cultivated, and a range of ecosystem benefits to be derived, sustainably for many hundreds of years (Box 8). It is clear that in these systems people and nature are intrinsically linked. However, these close relationships are under threat by the push to intensify rice production. The reasons to intensify rice production may be rational at the national level but clearly at the scale of a community or household the costs and benefits must be evaluated very carefully before deciding to follow the path of intensification. It is important that the development opportunities are realized without undermining the living aquatic resources on which so many people currently depend and which make a significant contribution to the resilience of rice systems.

Box 8: Importance of biodiversity in rice fields

Rice ecosystems throughout Southeast Asia often harbor a highly diverse set of organisms that provide multiple benefits, including pest control and maintenance of soil fertility, as well as being an important food source in their own right. From an ecosystems services perspective Some rice-based ecosystems contain more than 100 useful species: fish, crustaceans, molluscs, reptiles, amphibians, insects and plants (Halwart, 2008).

In relation to food, the individual “catch” from rice fields is usually modest. Much of what is caught is consumed and it is rarely sold. Consequently, it often goes unreported in official statistics. Yet this “invisible” fishery can be vitally important for livelihoods and peoples' wellbeing. In Laos they account for a large share of many people's intake of protein, micronutrients and essential fatty acids (Garaway et al., 2013).

Part II: Mitigation

As summarized in the updated NDC Synthesis Report,[3] collective progress in mitigation actions is observed to be progressing. Most of the 165 available NDCs (late 2021 numbers) include quantified mitigation targets. If all targets in the latest NDCs are implemented, the total global greenhouse gas (GHG) emissions in 2030 is expected to be 15.9% above the 2010 level. This, however, is not on track to limit global warming below 1.5 or 2 °Celsius, as the corresponding emission reductions need to be 45 or 25% compared to the 2010 level for the two targets to be met.

External events including the ongoing conflict in Ukraine, combined with other related factors will also likely derail many of the targets indicated in the NDCs since most of them were submitted before 2022[4], and therefore would likely lead to even higher emissions in 2025 and 2030 than projections in the NDC Synthesis Report. It is observed that in particular, targets related to energy and food system emissions would likely be affected the most.[5]

Increasing fossil fuel prices can also have a compounding effect on food security. Increasing prices of natural gas, a key ingredient of nitrogen-based fertilizers, and suspension of exports of fertilizer ingredients by certain countries is elevating prices of fertilizers which is likely to affect already vulnerable countries the most, [6] thereby undermining longer term poverty eradication efforts. This has the effect of exacerbating an already worsening situation where the world is experiencing shortage of grain, due to the reduced ability of Ukraine (one of the largest exporters) to export grains to the global market.

At this time, the provision of accurate data to navigate complex processes that effect specific targets in countries around the world is proving to be challenging. Although, tailored data and tools for tracking complex processes do not exist, alternative sources such as digital data and tools available at IWMI[7] can be useful in navigating intermediate steps such as monitoring food production systems and risks to prevent food (and embedded emission) losses. Moreover, often overlooked and relatively 'low-key'

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[3] UNFCCC. 2021.Nationally determined contributions under the Paris Agreement: Revised synthesis report by the secretariat. https://unfccc.int/sites/default/files/resource/cma2021_08r01_E.pdf

[4] UNFCCC. 2022. NDC Registry. https://unfccc.int/NDCREG

[5] Based on current observed trajectories both European and developing countries may delay phasing out their fossil fuel power plants., for example, Germany has recently decided, (albeit as a temporary measure) to extend operation of 11 fossil fuels and bring back online 16 dormant fossil fuel power plants, as a response to diminishing gas supplies from Russia. CNBC. 2022. Germany's increased coal, oil use will be temporary, Scholz says. *https://www.cnbc.com/2022/07/16/germanys-increased-coal-oil-use-will-be-temporary-scholz-says.html*

[6] NHK World. 2022. Food expert urges action on global fertilizer crunch. https://www3.nhk.or.jp/nhkworld/en/news/backstories/1978/

[7] IWMI. 2022. Digital data and tools https://www.iwmi.cgiar.org/resources/data-and-tools/

innovations such as replacing diesel pumps with solar pumps, restoring wetlands and mangroves or expanding fish friendly irrigation are some of the practices already utilized by developing countries that are less prone to the shocks of global developments and therefore can continue contributing to reducing emissions and improve food security.

IWMI's work on solar irrigation in South Asia for instance, is already helping national governments in Bangladesh, India, Nepal and Pakistan to achieve their GHG emission commitments[8] and can easily be transferred across and replicated in other regions of the globe to reduce emissions from their food systems. Similarly, fish friendly irrigation can lead to improved food security while minimizing environmental impacts in many developing countries across Asia and Africa (McCartney and Dubois 2021). Finally, since wetlands store up to two times more carbon per unit of land than forests[9] they are amongst the most effective terrestrial ecosystems for carbon sequestration. Dedicated focus on these areas of enquiry as possible mitigation actions can significantly expedite collective progress in mitigation and thus should be strongly advocated and supported.

Another valuable solution is wastewater reuse. Global water utilities currently account for nearly 2% of greenhouse gas emissions, a figure that is expected to more than double by 2040 as increasing demand for increasingly scarce water supplies rely on energy-intensive water supply methods such as desalination, large water transfers, and treatment. By 2030, global demand for water is expected to overtake sustainable supply by 40%.[10] On the other hand, wastewater treatment processes generate large amounts of sewage sludge which, if treated properly and integrated across sectors, can be used as agricultural fertilizer and act as a new source of bioenergy. Harnessing its power can unlock new resilience opportunities, enhancing food security and improving the health and wellbeing of millions. In many submitted NAPs and NDCs, the recycling of wastewater is identified as an important and under-utilized solution. Achieving its full potential requires low and high technology, policy and regulatory frameworks, and investment models which protect people and the environment.

Therefore, to make significant contributions to effective climate action through informed decision making, a comprehensive understanding of climate-related risks and the plethora of strategies that can be used to mitigate against them need to be considered. GHG reductions from the land-use sector will be essential as part of a suite of successful climate actions. Nature-based solutions, such as wetland protection and restoration, can provide an important means through which Parties can meet both climate mitigation and adaptation goals, while simultaneously providing a multitude of co-benefits for ecosystems, economies and societies.[11]

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[8] IWMI. 2022. What is Solar Irrigation for Agricultural Resilience in South Asia: Project Overview. https://solar.iwmi.org/

[9] EEA. 2022. Carbon stocks and sequestration in terrestrial and marine ecosystems: a lever for nature restoration? https://www.eea.europa.eu/publications/carbon-stocks-and-sequestration-rates

[10] World Water Day 2021: Global water community challenged to join the Race to Zero. https://www.water.org.uk/news-item/world-water-day-2021-global-water-community-challenged-to-join-the-race-to-zero/

[11] Anisha, N.F., Mauroner, A., Lovett, G., Neher, A., Servos, M., Minayeva, T., Schutten, H. & Minelli, L. 2020. Locking Carbon in Wetlands: Enhancing Climate Action by Including Wetlands in NDCs. Corvallis, Oregon and Wageningen, The Netherlands: Alliance for Global Water Adaptation and Wetlands International.

References Section I on adaptation

Bastakoti et al., 2016.

Bethancourt, H., Young, S., Northwestern University; Frongillo, E.A., University of South Carolina; Viviani, S., Cafiero, C., Food and Agriculture Organization of the United Nations, https://www.eurekalert.org/multimedia/937077 accessed 03/08/22.

Brindha, K. and Pavelic, P. 2016. Identifying priority watersheds to mitigate flood and drought impacts by novel conjunctive water use management strategies. *Environmental Earth Sciences*.

Domènech, L. 2015. Improving irrigation access to combat food insecurity and undernutrition: A review. Global Food Security 6, 24–33.

Garaway, C.J., Photitay, C., Roger, K., Khamsivilay, L. and Halwart, M. 2013. Biodiversity and nutrition in rice-based ecosystems; a case of Lao PDR, Human Ecology (41) 457-562.

Global Water Partnership (GWP) 2012. Groundwater Resources and Irrigated Agriculture. Global Water Partnership Perspectives Paper. Global Water Partnership. Stockholm, Sweden. GWP IWRM ToolBox: www.gwptoolbox.org.

IEG (Independent Evaluation Group). 2012. *Adapting to Climate Change: Assessing the World Bank Group Experience*. Washington, DC: World Bank.

International Water Management Institute (IWMI). 2015. *Improving water management in Myanmar's dry zone for food security, livelihoods and health.* Colombo, Sri Lanka: International Water Management Institute (IWMI). 52p. doi: 10.5337/2015.213.

Izzi, G., Denison, J., Veldwisch, G.J. eds. 2021. The Farmer-led Irrigation Development. Guide: A what, why and how-to for intervention, The World Bank https://pubdocs.worldbank.org/en/751751616427201865/FLID-Guide-March-2021-Final.pdf.

James, A.J., Bahadur, A.V. and Verma. S. 2018. Climate resilient water management: an operational framework from South Asia. Action on Climate Today, Learning Paper. https://reliefweb.int/sites/reliefweb.int/files/resources/OPM_WaterManagement_Pr4Final_WEB.pdf accessed 23/02/19.

Jones, L., & Boyd, E. 2011. Exploring social barriers to adaptation: Insights from Western Nepal. Global Environmental Change, 21, 1262–1274.

Milly, P.C.D.; Betancourt, J.; Falkenmark, M.; Hirsch, R.M.; Kundzewicz, Z.W.; Lettenmaier, D.P.; Stouffer, R.J. 2008. Stationarity is dead: Whither water management? *Science* 319: 573-574.

Passarelli, S., Mekonnen, D., Bryan, E., Ringler, C. 2018. Evaluating the pathways from small-scale irrigation to dietary diversity: evidence from Ethiopia and Tanzania. Food Security 10(4), 981–997.

Pavelic, P., Srisuk, K., Saraphirom, P., Nadee, S., Pholkern, K., Chusanathas, S., Munyou, S., Tangsutthinon, T., Intarasut, T. and Smakhtin, V. (2012). Balancing-out floods and droughts: Opportunities to utilize floodwater harvesting and groundwater storage for agricultural development in Thailand. Journal of Hydrology 470–471:55–64.

Ray and Brown, 2015.

Rosa, L., Chiarelli, D. D., Rulli, M. C., Dell'Angelo, J., D'Odorico, P. 2020. Global agricultural economic water scarcity. Sci. Adv. 6, eaaz6031.

Shah, T. 2014 Groundwater Governance and Irrigated Agriculture. TEC Background Paper 19. Global Water Partnership. Stockholm, Sweden.

Taylor, R.G., Scanlon, B., Döll,P., Rodell, M., van Beek, R., Wada,Y., Longuevergne, L., Leblanc, M., Famiglietti,J.S., Edmunds, M., Konikow, L., Green, T.R., Chen, J., Taniguchi, M., Bierkens, M.F.P., MacDonald, A., Fan, Y.,Maxwell, R.M., Yechieli, Y., Gurdak, J.J., Allen, D.M., Shamsudduha, M., Hiscock,K., Yeh, P, Y-F., Holman, I. and Treidel, H. (2012) Ground water and climate change. Nature Climate Change 3, 322–329. doi:10.1038/nclimate1744.

University of Warwick, 2002. Very-low-cost domestic roof-water harvesting in the humid tropics: existing practice. DFID KAR Contract R7833. Development Technology Unit. School of Engineering, University of Warwick. 106 pages.

UN Water. 2010. *Climate Change Adaptation: The Pivotal Role of Water*. Geneva: UN Water.

Vörösmarty, C.J., Green, P., Salisbury, J. and Lammers, R,B. 2000. Global Water Resources: Vulnerability from Climate Change and Population Growth. Science 14, 284-288.

Wang, X-j., Zhang, J-y., Shahid, S., Guan, E-h., Wu, Y-x., Goa, J. and He, R-m 2016. Adaptation to climate change impacts on water demand. Mitigation and Adaptation Strategies for Global Change 21, 81-99.

Wang, M.J. 2013. Report 2: water harvesting and water management options for agricultural communities in Laos. IRAS project: improving the resilience of the agriculture sector in Lao PDR to Climate Change Impacts. Vientiane, 49 p.

Woodhouse, P., Veldwisch, G.J., Venot, J.P., Brockington, D., Komakech, H., Manjichi, A. 2016. African farmer-led irrigation development: Re-framing agricultural policy and investment?, Journal of Peasant Studies 44:1, 213–233.

References Section II on Mitigation

Anisha, N.F., Mauroner, A., Lovett, G., Neher, A., Servos, M., Minayeva, T., Schutten, H. & Minelli, L. 2020. Locking Carbon in Wetlands: Enhancing Climate Action by Including Wetlands in NDCs. Corvallis, Oregon and Wageningen, The Netherlands: Alliance for Global Water Adaptation and Wetlands International.

CNBC. 2022. Germany's increased coal, oil use will be temporary, Scholz says. https://www.cnbc.com/2022/07/16/germanys-increased-coal-oil-use-will-be-temporary-scholz-says.html.

EEA. 2022. Carbon stocks and sequestration in terrestrial and marine ecosystems: a lever for nature restoration? https://www.eea.europa.eu/publications/carbon-stocks-and-sequestration-rates.

IWMI. 2022. Digital data and tools https://www.iwmi.cgiar.org/resources/data-and-tools/.

IWMI. 2022. What is Solar Irrigation for Agricultural Resilience in South Asia: Project Overview. https://solar.iwmi.org/.

McCartney, M & Dubois, M. 2021. Fish friendly irrigation: Enhancing production, livelihoods and health. https://digitalarchive.worldfishcenter.org/handle/20.500.12348/4878.

NHK World. 2022. Food expert urges action on global fertilizer crunch. https://www3.nhk.or.jp/nhkworld/en/news/backstories/1978/.

UNFCCC. 2021.Nationally determined contributions under the Paris Agreement: Revised synthesis report by the secretariat. https://unfccc.int/sites/default/files/resource/cma2021_08r01_E.pdf.

UNFCCC. 2022. NDC Registry. https://unfccc.int/NDCREG.

World Water Day 2021: Global water community challenged to join the Race to Zero. https://www.water.org.uk/news-item/world-water-day-2021-global-water-community-challenged-to-join-the-race-to-zero/

IWMI sources and initiatives

Initiatives and projects

ClimBeR: Building Systemic Resilience Against Climate Variability and Extreme
https://www.cgiar.org/initiative/23-climber-building-systemic-resilience-against-climate-variability-and-extremes/

CWANA: From Fragility to Resilience in Central and West Asia and North Africa
https://www.cgiar.org/initiative/10-from-fragility-to-resilience-in-central-and-west-asia-and-north-africa-f2r-cwana-transforming-responses-to-drought-and-climate-variability/

NEXUS Gains: Realizing Multiple Benefits Across Water, Energy, Food and Ecosystems
https://www.cgiar.org/initiative/28-nexus-gains-realizing-multiple-benefits-across-water-energy-food-forest-biodiversity-systems/

Mitigate+: Research for Low-Emission Food Systems https://www.cgiar.org/initiative/32-mitigate-plus-research-for-low-emission-food-systems/
Transforming Agrifood Systems in South Asia https://www.cgiar.org/initiative/20-transforming-agrifood-systems-in-south-asia-tafssa/

Ukama Ustawi: Diversification for Resilient Agrifood Systems in East and Southern Africa https://www.cgiar.org/initiative/21-ukama-ustawi-u2-water-secure-and-climate-resilient-agricultural-livelihoods-in-east-and-southern-africa/

MENAdrought https://menadrought.iwmi.org/

Pioneering a Holistic approach to Energy and Nature-based Options in MENA for Long-term stability - PHENOMENAL https://devtracker.fcdo.gov.uk/projects/GB-GOV-1-301142/summary

Other sources:

IWMI water adaptation meta-review https://www.aciar.gov.au/publication/technical-publications/effectiveness-water-adaptation-responses-reducing-climate-related-risks-a-meta-review

Mapping Multiple Climate-related Hazards in South Asia, IWMI Research Report https://www.iwmi.cgiar.org/publications/iwmi-research-reports/iwmi-research-report-170/

How hi-tech insurance is helping farmers survive floods https://www.iwmi.cgiar.org/success-stories/how-hi-tech-insurance-is-helping-farmers-survive-floods/

How a new framework can provide flood insurance guidance to millions of farmers https://www.iwmi.cgiar.org/2021/08/how-a-new-framework-can-provide-flood-insurance-guidance-to-millions-of-farmers/

Adaptation to Climate Variability in Sri Lanka: A Case Study of the Huruluwewa Irrigation System in the Dry Zone, IWMI Working Paper https://www.iwmi.cgiar.org/publications/iwmi-working-papers/iwmi-working-paper-200/

Building climate resilience and adaptive capacity in Sri Lanka: the bundled insurance solution https://cgspace.cgiar.org/handle/10568/113763

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