Aqua 4 Sudan Partnership

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Adapting to impacts of changing rainfall in rural Sudan through an IWRM approach

Technical Paper

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INTRODUCTION

The Aqua4Sudan partnership in Sudan consists of International Aid Services (IAS), Islamic Relief Worldwide (IRW), Practical Action, Plan Sudan, SOS Sahel, World Relief and ZOA. This partnership implements the Rural Water for Sudan program in 6 states, namely Red Sea, Kassala, Al Qadarif, North Darfur, West Darfur and South Darfur, with funding from UKaid and the EU. Their operational areas are covering 21 catchment areas in those states, as shown in Figure A1 and Table A1.

Aim of this paper:

This technical paper has three broad aims:

- To review current and projected changes in rainfall patterns in Sudan and their impact on smallholders and pastoralists in Sudan at the sub-catchment level.
- To recommend adaptation strategies for each of the current and anticipated impacts.
- To describe how the adoption of an Integrated Water Resources Management (IWRM) approach could help leverage these adaptation strategies. This would increase the resilience of smallholders and pastoralists in the face of potential climate change impacts. Also, it would diminish the competition between communities over limited resources. Finally it would improve weak sectored and top-down governance and policy framework structures.

2 CLIMATE VARIABILITY AND CLIMATE CHANGE

The atmosphere has been described as "a heat engine driven by the sun" (Bryson, 1974). The distribution of heating and cooling of the atmosphere results in a primary or general circulation that interacts with the broadest terrain and generates large-scale waves and eddies, thus producing the climatic pattern of the world. Thereforeany heat engine controls internal or extrinsic to these internal mechanisms of the atmosphere itself" can cause changes in the climate. Consequently, many factors and processes that affect the intensity and distribution of sunlight reaching the Earth, the transmittance of the atmosphere or the reflectivity of the earth-atmosphere, can cause climate to shift (Ibid.).

Climate change describes a change in the average conditions of the usual weather in a certain area taking place over a long period of time (e.g. hundreds or even millions of years). For instance, a change of rainfall could occur in its amount per year or season, in the timing or length of a rainy season, or in frequency of and intensity of rain. A change could also occur in the usual levels of temperatures during a winter or a summer season. While climate change is ascribed to human interventions, climate variability is mostly attributed to natural oscillations in the Earth's systems (Hare, 1993; Wigley, 1999).

The factors leading to shifts in climate could result from natural processes and/or human interference. Examples of the former are changes in the earth's distance to the sun, the energy the earth (specifically the oceans) receives from the sun, or vulcanic eruptions. An example of the latter is pollution of the atmosphere. This happens because of energy-consuming activities and fossil fuels (in cars or for heating and cooking), which emit gases to the air and consequently the air is heated up. In this regard, the climate of the entire Earth has been changing over the last century – referred to as global climate change. This change includes warming temperatures and changes in precipitation. It is featured by, for example, rising sea levels, shrinking mountain glaciers and melting ice at a high-rate. As per the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (Trenberth, 2007), observations have shown, among others, the following trends:

- Warming of land at a faster rate than the oceans
- Average temperatures increased in the arctic at almost twice the global surface
- Changes in extremes of temperature
- Increase precipitation over land north of 30°N over the period 1900 to 2005 but dominant downward trends in the tropics since the 1970s.
- Substantial increases in heavy precipitation events.
- Changes in the large-scale atmospheric circulation
- Increased intense tropical cyclone activity since about 1970.

Climate change and variability has been a key topic of heightened concern among scientists, politicians, economists and the public. Addressing climate variability and climate change is a significant challenge for understanding the effects of greenhouse gas (GHG) warming in a given region or locality. Such an assessment is particularly critical for areas which encompass different hydro-climatological zones.

3 RAINFALL AND ITS IMPORTANCE AND RELATION TO DIFFERENT LIVELIHOODS

Humans whose livelihood depend on rainfed agricultural activities become substantially impacted if they live in regions prone to large inter-annual rainfall variability. In this case, the local food and livelihood security is directly impacted by increasing rainfall variability, given the fact that most households depend on rainfed subsistence agriculture. Households derive their livelihood from food crop and livestock productions. On the one hand, farming activities in hyper-arid, arid and semi-arid regions are already limited by a lack of rainfall, thus leading to a loss of farming production and limited harvest. On the other hand, farming activities in humid regions are also sensitively affected by any increase in the accumulated annual rainfall, which increases the value of land and/or decreases the yield levels (Ruano and Milan, 2014). High intensity of rain increases the rate of soil erosion and, thus, land degradation especially in deforested lands. The consequence is a decrease in soil fertility, agricultural productivity and food availability.

Rainfall variability and food and livelihood security have a direct impact on household decisions on mobility and migration. Temporary, seasonal and internal (rural–rural) migration is a traditional source of non-farm income driven by rainfall-related hazards - such as floods, landslides and droughts, environmental land degradation - and economic, demographic and social and political factors (Kollmair and Banerjee, 2011). If climate-induced forces escalate, while mitigating measures are not diversified and internal migratory opportunities do not exit, households may migrate from rural areas to urban areas as a risk management strategy. In the worst case when the risk culminates or protracts, households may be forced to abandon farming. Additionally, such communities usually have high percentages of malnourished children.

4 RAINFALL AS PART OF CATCHMENT SCALE HYDROLOGICAL CYCLE

Generally, the water cycle - also known as a hydrological cycle - describes the continuous movement of water on, above, and below the surface of the earth (USGS, nd). However, it is a more complex system that includes many different processes. Throughout its movement, it changes its status between liquid, vapor and ice due to the energy exchange between the sun and the earth (Stagl et al., 2014). On the catchment scale, the hydrological cycle comprises precipitation in its various forms (rainfall, snowfall, fog, drizzle, etc.), various transfer processes (i.e. evapotranspiration, infiltration, and surface runoff), and different storages and outputs.

Figure 1 shows a schematic representation that summarises the hydrological cycle components on the catchment scale. Rainfall type, volume, and intensity are the main factors that govern other processes in the catchment scale. When precipitation falls to the earth, part of it is **intercepted** by plants and trees and evaporates back to the atmosphere through transpiration. Part of the amount reaching the surface of the earth **infiltrates** into the soil, and the remaining water flows as **surface runoff** to join streams. Small streams join others to form rivers that ultimately pour into a lake or discharge into the ocean. Some of the infiltrated water evaporates or is used by plants, and some of it contributes to the streams as **baseflow** or appears in the surface as springs. The remaining part of the infiltrated water percolates deep through the soil and pores of rocks into the groundwater. Liquid water **evaporates** from streams, soil and plant surfaces. Subsequently, the water vapor **condenses** to form clouds. The wind **transports** the clouds to other locations and the water from the clouds **precipitates** back to earth in the form of rain and snow.

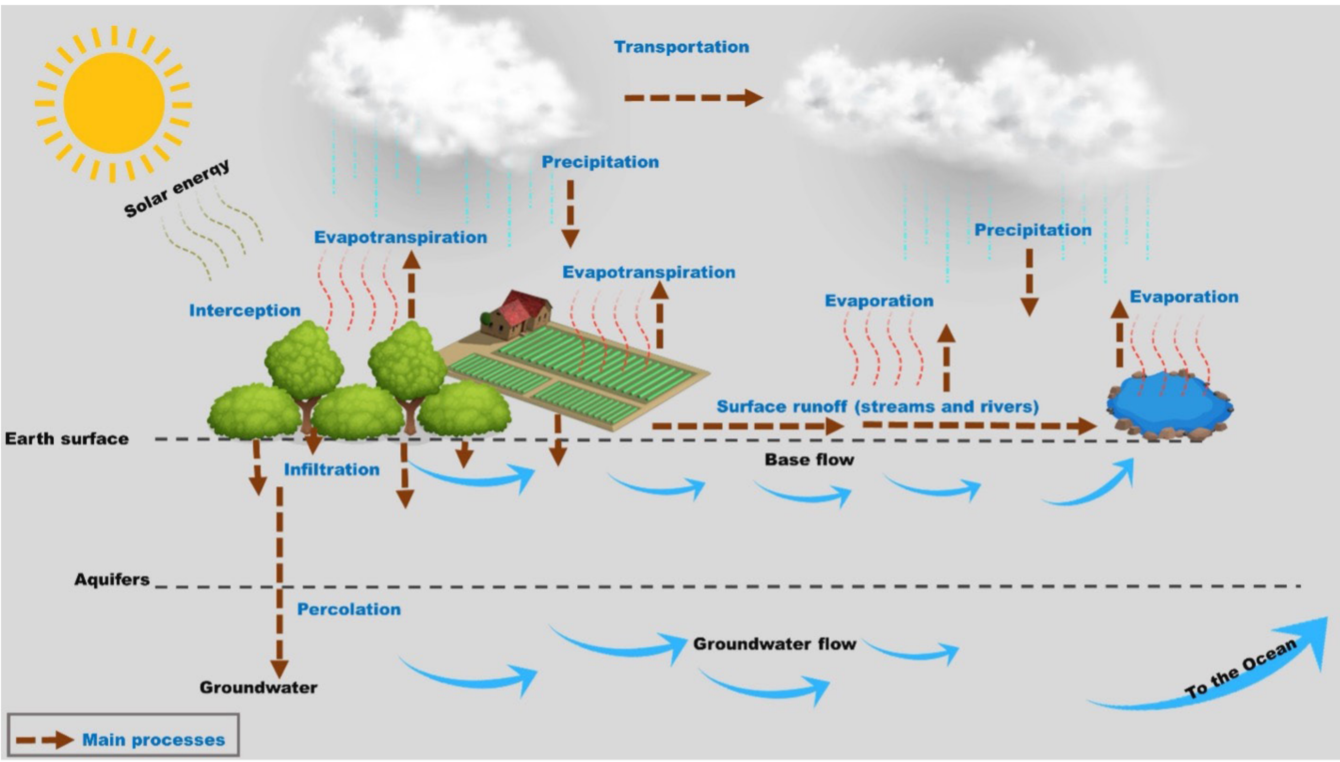


Figure 1 Schematic representation of the hydrological cycle components on catchment scale.

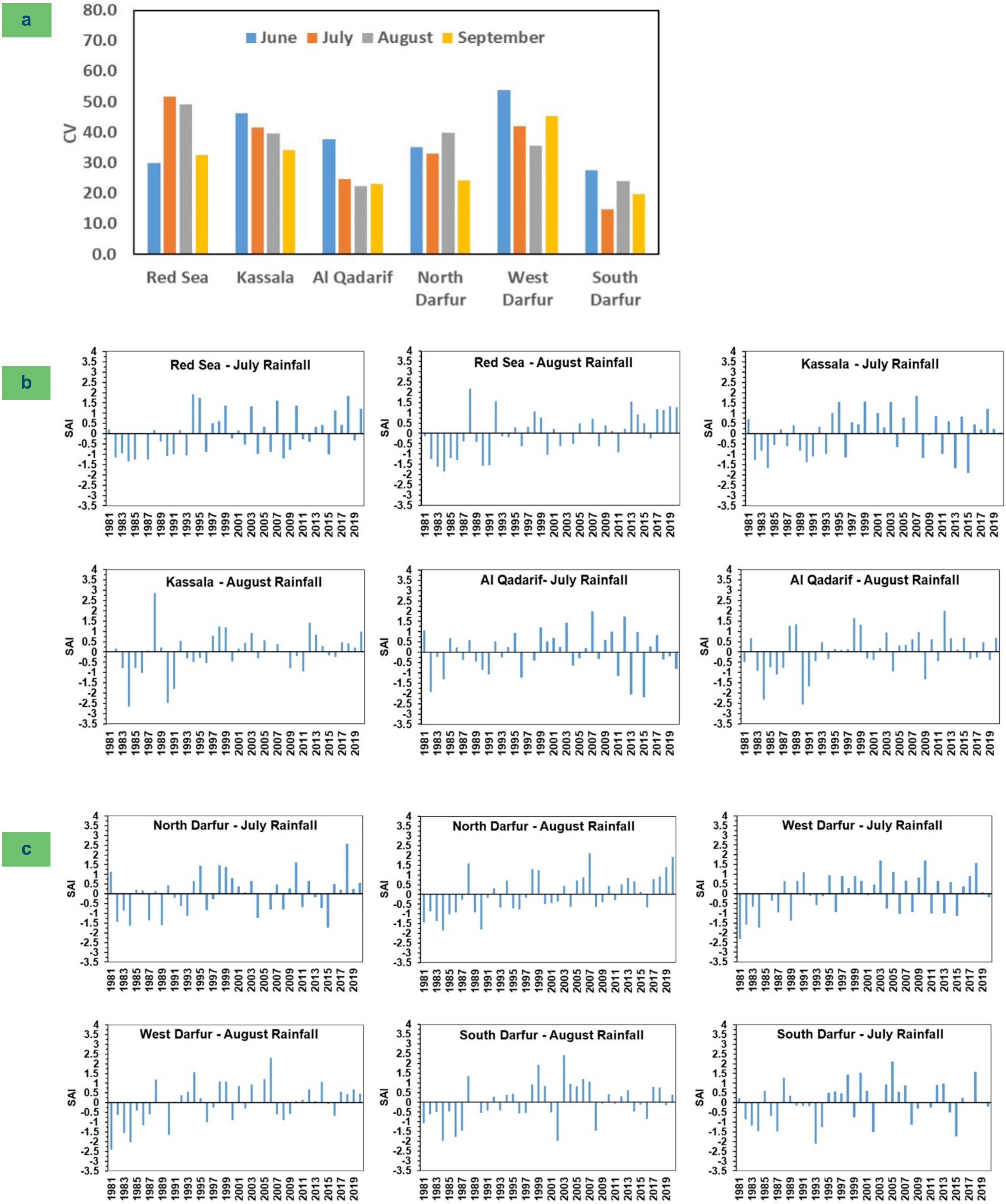
5 OVERVIEW OF PAST AND CURRENT SITUATIONS AS WELL AS PROJECTED "CHANGES" IN RAINFALL PATTERNS IN SUDAN

Rainfall in Sudan is known to be highly variable in time and space and is subject to increase and decrease. During the 20th century, particularly between 1921-50 and 1956-85, the annual rainfall in the arid and semi-arid part of the country "has declined by 15 percent, the length of the wet season has contracted by three weeks, and rainfall zones have migrated southwards by between 50 km and 100 km" (Hulme, 1990). This had to do more with a reduction in the rainfall frequency than in its intensity. The decline reported in western Sudan since 1966 was mainly due to reduced rainfall amounts during July to September (Eldredge et al., 1988). August is usually the wettest month in the arid and semi-arid hinterland. Despite the speculation of a recovery from the Sahelian drought, Elagib and Elhag (2011) found a significant decline in rainfall over the northern half of the country. They noted that the 2000s were drier in general and knew a longer dry season than the 1970s and the 1980s. They argue that reduced rainfall is not the only factor contributing to the drought that should be considered. Temperature is also on the rise, making rainfall less effective due to high evaporation. Indeed, there is mounting evidence of increasing temperature levels in Sudan, with a maximum rate of 0.45 °C rise in nighttime temperature per decade temperature and 0.34 °C rise in daytime temperature per decade over the period 1941-2005 (Elagib, 2010). There is evidence of a clear dependency on annual rainfall on the very strong rainfall events (i.e., daily rainfall of > 30 mm) as reported by Elagib (2010) and Mahmoud et al. (2014). Goenster et al. (2015) detected that an increase of low daily rainfalls (< 3 mm) coincided with a decline in medium daily rainfall events (10 to 20 mm).

Several of the above-said characteristics can be seen in Figure 2, which shows the rainfall data of the ZOA case-study areas for the years 1981 to 2020. For this analysis, the Climate Hazards Group Infra-Red Precipitation with Stations (CHIRPS) version 2.0 rainfall product was selected due to its long time series (1881 to date) and its high performance across East and sub-Saharan Africa (Dinku et al., 2018; Harrison et al., 2019). The CHIRPS dataset is developed and maintained by the U.S. Geological Survey (USGS) and the Climate Hazards Group of the University of California (Funk et al., 2015). As shown in the figure, rainfall is highly variable from one month to another (intra-annually: Figure 2a) and from year to year (intra-annually: Figure 2b). Both types of variability follow a north-south gradient, thus showing the highest variability in the arid areas (Red Sea, Kassala and North Darfur) to the semi-arid areas (Al Qadarif and South Darfur). Sulieman and Elagib (2012) and Elagib et al. (2017) reported evidence of reduced reliability of rainfall. This was concluded based on the increasing rainfall variability during the beginning and end of the rainy season in Al Qadarif, North Darfur and South Darfur.

Future predictions for Sudan for the periods of 2011–2030, 2046–2065, and 2080–2099 showed decreasing trends in the main rainy season (June, July, and August) and an increasing trend in September, October, and November (Chen et al., 2013). Temperature increases are projected in most parts of Sudan combined with a reduction in rainfall and changes in the wet and dry spells (Osima et al., 2018).

Figure 2. CHIRPS-based estimates of rainfall anomalies and variability during the last four decades expressed as a) Coefficient of Variation (CV), b) Standardized Anomaly Indexes (SAIs)for northern states and c) SAIs for Darfur states respectively. SAIs are the deviation of rainfall from a mean expressed as a number of standard deviations. CV is a statistical measure of dispersion of rainfall expressing the ratio of standard deviations to the mean of the data.



6 EXPECTED IMPACTS OF POTENTIAL CHANGES IN RAINFALL PATTERNS ON KEY SECTORS IN SUDAN: IS THERE A FUTURE PROBLEM?

According to the Intergovernmental Panel on Climate Change (IPCC, 2013), rural regions in developing countries are most exposed to climate change. Droughts are expected to be amplified by temperature and rainfall changes, and particularly by the increase of both factors. This would likely have a negative impact on livelihoods in the arid and semi-arid lands. This risk calls for the formulation of actionable policies to adapt and mitigate the impacts of global warming levels (Chen et al., 2013; Osima et al., 2018). This section provides an overview of the potential impacts of climate change – particularly the changes in rainfall patterns - on key sectors and communities in Eastern Sudan and the Darfur region, where Aqua4Sudan partnership Sudan implemented projects.

Potential impacts on rural water supply in non-Nilotic Sudan

One of the main aspects of climate change and its impact on water resources is precipitation. In many African countries, rainfall variability affects the annual and seasonal runoff. Hence widespread droughts and floods occur. This poses a substantial challenge to water availability, quality and supply services, especially in rural areas (Guatam, 2006; Macdonald et al., 2009; Georgakakos et al., 2014). People living in rural (non-Nilotic) areas in Sudan rely mainly on vulnerable and unimproved water sources such as open water and shallow wells. The rural water supply services in those areas are significantly affected by annual and seasonal rainfall variability. Rainfall seasonality affects water access in terms of quality, availability and water point functionality. This way, areas in the east of Sudan and in the Darfur states are likely to be most affected by climate change. However, other drivers like population growth and rising food demands are likely to provide more significant pressure on rural water supplies (Bonsor et al., 2010). Key expected impacts of potential changes in rainfall patterns on rural water supply in non-Nilotic areas in Sudan are summarized in the following bullet points:

- Increased intensity and irregularity of rainfall with future climate change will change the seasonality of runoff, peak flows, and sediment load, which will lead to unreliable water supply in some areas and destructive flash floods in others.
- Seasonal rivers (wadis) in years of drought and extended drought periods will possibly dry up.
- Existing water harvesting infrastructure might be destroyed or filled with sedimentation.
- As rainfall and surface waters become less reliable, the demand for groundwater-based supplies is likely to increase further. Dependence on shallow groundwater will lead to a high risk of over-abstraction of the groundwater aquifers and thus more water scarcity.
- Groundwater recharge rates from seasonal streams and wadis will be reduced.
- People from areas with scarce water resources might be displaced. This will amplify the consequences of climatic change for areas with limited water resources. It will further exacerbate environmental degradation, waterborne diseases, poor water quality, and socio-economic disruptions and conflicts over the available limited water resources (HCENR, 2016).
- The salinity of coastal lagoons and groundwater wells might increase in coastal areas like the Red Sea state (HCENR, 2016).

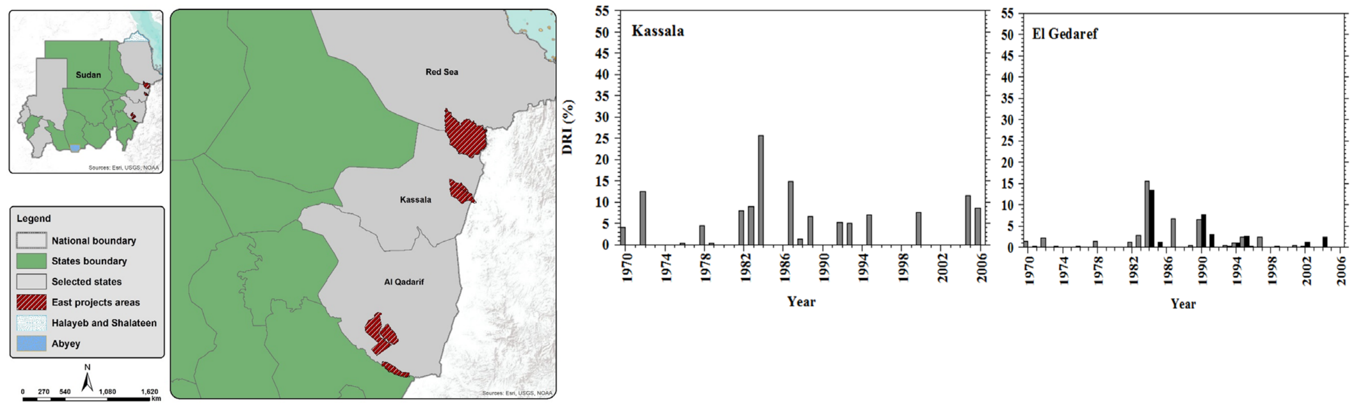
As there are too many uncertainties, it is difficult to predict and quantify the likely impacts of climate change on rural water supplies from climate model projections. However, examining how the different water resources in non-Nilotic rural areas in Sudan respond to existing and future rainfall variability can provide an insight into the likely effects of climate change. Quantifying such changes is beyond the purpose of the present report, but it is likely that surface water resources will become increasingly unreliable. To adapt to the potential impacts of climate change on water resources in general, improvements of water management and assessments of groundwater reserve should be carried out. Also, more water harvesting techniques should be explored and wells and boreholes should be dug in areas safe from pollution. In addition, IWRM plans at state and catchment levels should be developed.

Potential impacts on on the agro-pastoralism sector

Any change in the rainfall patterns has important implications for the different human activities, production sectors and availability of resources. For example, any decline in rainfall during July to September is critical for traditional rain-fed irrigation, on which agriculture in Sudan is largely based. An increase in low rainfall events, combined with a decrease in medium intensity rains harms crop production since such changes affect the water balance (Goenster et al., 2015). It is not helpful to agricultural activities and production if the concentration of the total growing season rainfall is distributed by a small number of high intensity rainfall events. Rather, a better rainfall distribution during the course of the season results in a better cropland performance (Sulieman and Elagib, 2012).

The farmers' choice of an appropriate sowing date interacts significantly with the onset of the rainy season. Bussmann et al. (2016) found that farmers in Al Qadarif postpone the sowing date of sorghum to the end of July, or sometimes even to the beginning of August, to ensure sufficient moisture availability for sowing sorghum. However, they found this delayed sowing date to be unsafe because of the high probability of subsequent dry spells. If the dry spells occur, they will lead to reduced sorghum productivity. In fact, Elagib (2015) showed evidence that drought occurrence during the early growing season (June and July) negatively affect the sorghum and millet yields in the Sahel zone of Sudan, including in the ZOA case study areas (Figure 3). For instance, the two crops in Northern Darfur happened to face a crop failure risk of up to 81% and 73%, respectively (Elagib, 2015). Crop production in Western Sudan is particularly impacted by overall drought during the growing season (Elagib, 2014). Unreliable rainfall and dry spells have caused famine among the rural population and hunger-vulnerable groups within the urban centers (Ibrahim 1988, 1994; Webb et al. 1991; Bakhit, 1994). Elagib et al. (2017) found that farmers in the Darfur region seem to be better aware of rainfall changes during the critical time for their crop than of long-term patterns in temperature and within-rainfall variability. Such a finding suggests that there is a need for improving the data network, and for facilitating weather monitoring and early warning systems in the region (Elagib et al., 2017).

a



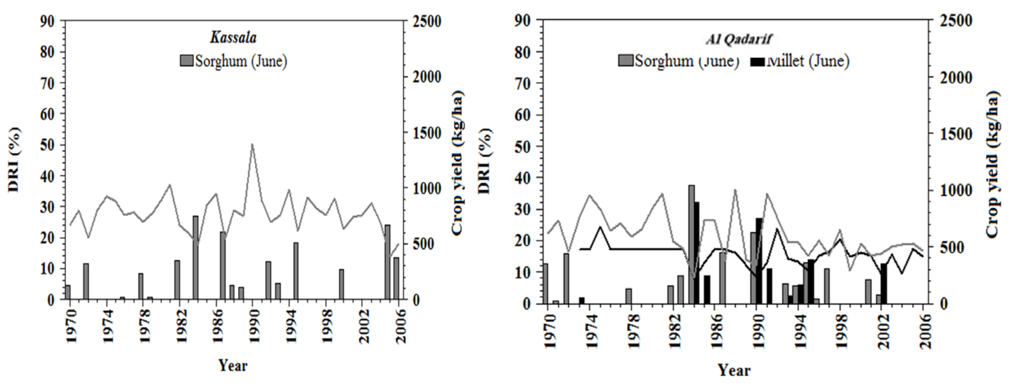


Figure 3 Temporal Drought Risk Index (DRI) yields for sorghum (black) and millet (grey) during the full and early growing season: a) Eastern Sudan and b) Darfur. DRI estimates the probability (possible outcomes) of drought disaster to crop yield. (Source: Adapted from Elagib, 2014, 2015).

b

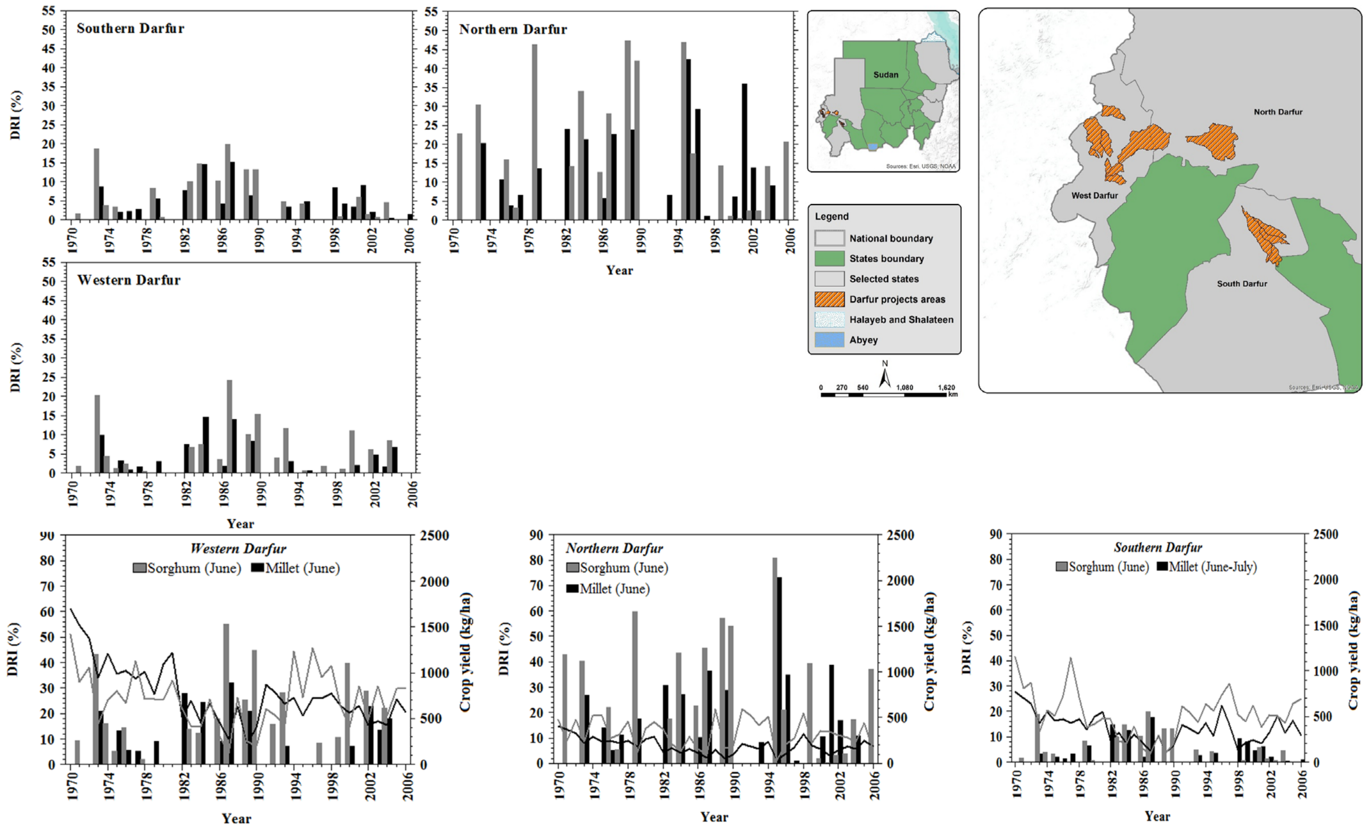


Figure 3 (continued)

During the period of changing rainfall properties to date, there has been escalating land clearance for agricultural expansion at the expense of pasture areas in Al Qadarif (Sulieman and Buchroithner, 2009; Sulieman and Elagib, 2012; Sulieman and Ahmed, 2013). These trends in the expansion of cropping area are likely to continue because of climate change and a growing population.

Based on the above overview of shifting climates and on the National Adaptation Plan published by HCENR (2016), it is possible to highlight the following climate change risks for the ZOA sites:

- **North Darfur:** Crop failure due to inadequate or highly variable rainfall in combination with a lack of awareness of best practices and with poor agricultural policy
- **West Darfur:** Adverse impact on crop yield and further deterioration of rangelands
- **South Darfur:** Threatened animal production because of acceleration of the disappearance of suitable rangeland species
- **Kassala:** Intensifying occurrence of floods and drought, thus increasing the number of vulnerable rural populations
- **Al Qadarif:** Intensification of impacts on crop production and deterioration of forests, which represent a major part of the state's economy
- **Red Sea:** Increase in the threat to livelihoods for agro-pastoralist communities as a result of the likely expanding gap between supply of and demand for production

7 OVERVIEW OF CLIMATE CHANGE IMPACTS AND PROPOSED ADAPTATION MEASURES

Table 2 gives an overview of some proposed adaptation measures for each identified impact in the selected states based on Sudan's National Adaptation Plan (NAP) developed by the Higher Council for Environment and Natural Resources (HCENR, 2016) and the authors' point of view. Adopting the suggested adaptation measures in the above-mentioned sectors should contribute to minimizing or overcoming the expected impacts of potential changes in rainfall patterns. It should also improve the sustainability of the natural resources generally and overall water and food security particularly in the targeted rural areas. Ultimately it should contribute to sustained livelihoods for the people.

Table 1 Suggested adaptation strategies for the expected impacts of changing rainfall patterns on key sectors in Sudan in addition to strategies and interventions implemented by the Aqua4Sudan parternship

Sector	Potential impact	Suggested adaptation strategies	Aqua4Sudan implemented strategies
Red Sea			
Rural water supply	• Frequent flash floods and high sedimentation load in the seasonal rivers like Baraka • High salinity of coastal lagoons and groundwater wells in the coastal areas • Infeasibility and inefficiency in surface water harvesting because of an increase in rainfall variability, low rainfall, high evaporation rates, and extreme temperatures	• Drilling of new water wells and rehabilitation of old wells • Constructing suitable water harvesting methods like sub-surface dams • Improving water harvesting techniques • Establishing desalination stations along the Red Sea • Developing and implementing IWRM plans at states and catchments levels	*In Dordeib and Khor Arab Catchments, Red Sea:* **Water supply:** 59 hand pumps, 20 mini water yards, 3 water yards, 1 small water supply network and 7 hand-dug wells **Water harvesting and GW Recharge:** 2 hafeers, 1 check dam, 9 sand dams and 1 subsurface dam **IWRM Plans:** 2 community led IWRM plans were developed for the two catchments
Smallholder farmers in rainfed irrigation	• Widening of the gap between production and demand in key crop groups	• Providing certified drought-resistant seed stocks • Introducing water harvesting techniques • Diversifying crop structure • Providing agriculture extensions • Setting up an early warning system	Drought resistance seeds distributed along 2 corridors, 2 diversion structures implemented, agriculture extension service provided for famer groups in both catchments

Sector	Potential impact	Suggested adaptation strategies	Aqua4Sudan implemented strategies
Pastoralism and grazing areas	• Increase in the pace of the already rapidly deteriorating rangeland	• Rehabilitating forests and afforesting • Seeding collection and reseeding of forests • Enclosing endangered species, pastures and farms • Improving the quality of livestock fodders • Enforcing laws and regulations	Tick treatment campaigns conducted, veterinary service provided, animal shelters constructed as well as broadcasting with fodder seeds
Kassala			
Rural water supply	• Decrease in agricultural productivity • Frequent seasonal flooding from the Gash and Atbara rivers in the western part of the state • Increase in water contamination and waterborne diseases • Infeasibility of harvesting rainwater because of frequent drought (like the two recent major droughts occurring in 2008 and 2011)	• Drilling more wells • Improving water harvesting techniques • Eradicating invasive mesquite trees from water source areas • Setting up awareness-raising programs to help farmers adopt more efficient and modern irrigation system • Rehabilitating hafeers and water harvesting structure to provide the additional water needed to enable grazing on remote/rural pastures • Developing and implementing IWRM plans at states and catchments levels	*In Hamashkorieb, North Delta, Darrasta, Telkok, Tahaday and Adurut Catchments, Kassala:* **Water supply:** 36 hand pumps, 52 mini water yards, 7 water yards, and 3 hand-dug wells **Water harvesting and GW Recharge:** 1 hafeer, 4 GW recharge basins, 2 in stream drift structures, 4 check dams, 1 sand dam and 9 subsurface dams **IWRM Plans:** 5 community led IWRM plans were developed for all catchments
Smallholder farmers in rainfed irrigation	• Decrease in agricultural productivity	• Implementing agroforestry to limit flooding	
Pastoralism and grazing areas	• Decline of pastures • Disappearance of pasture species	• Enabling remote grazing by rehabilitating available hafeers in rural areas • Managing forests and mesquites by reseeding with favorable and indigenous specie.	3 hafeers rehabilitated, mesquite management campaigns carried out in three catchments
Al Qadarif			
Rural water supply	• Frequent drought and decreasing rainfall • Insufficient harvesting rainwater water for rural water supply	• Setting up a permanent pipeline from the reservoir of Dam complex of Upper Atbara would help alleviate water scarcity • Capacity building on water harvesting techniques • Developing and implementing IWRM plans at states and catchments levels	*In Gala Alnahal, Albutana, Mahala, Alsaraf, wadowdieda and ban Degio catchments:* **Water supply and Harvesting:** 15 haffirs, 4 tap stands (Kisok), 28 check dams,14 hand pump, 23 mini water yards **IWRM Plans:** 5 community led IWRM plans were developed for all catchments

Sector	Potential impact	Suggested adaptation strategies	Aqua4Sudan implemented strategies
Smallholder farmers in rainfed irrigation	• Decrease in agricultural productivity	• Cultivating sorghum alongside other crops meant for animal production • Putting in place early warning systems, as well as building capacity and raising awareness	Deep chiseling as water conservation was applied in 2975 feddan targeting 443 farmers
Pastoralism and grazing areas	• Emergence of animal diseases • Decrease in pasture and its species • Decline of tree cover • Increase of food security gap	• Introducing animals into agricultural rotations • Introducing improved plant and animal breeds	Training and supplying improved seeds broadcasted along 4 corridors
North Darfur			
Rural water supply	• Acute groundwater depletion • Possible drying of the seasonal rivers (wadis) in years of droughts and extended drought periods	• Digging more wells and boreholes in areas that are safe from pollution • Introducing more sand and sub-surface dams to increase the water buffering and groundwater recharge • Building capacity on water harvesting techniques • Developing and implementing IWRM plans at states and catchments levels	*In wadi Bargo (Kabkabya) Catchment, North Darfur:* **Water supply and Harvesting:** 6 check dams, 10 sand dams, 4 subsurface dams, 31 hand pumps, 3 water yards and 12 improved hand dug wells **IWRM Plans:** 1 community led IWRM plan was developed
Smallholder farmers in rainfed irrigation	• Crop failure	• Changing policy to discourage malcultivation practices • Introducing improved crop varieties and horticultural crops • Setting up shelterbelts • Implementing crop rotation • Building capacity on water harvesting techniques • Setting up more efficient irrigation systems • Diversifying household income sources • Transferring technology and technical know-how	Improved crop seeds were introduced along with capacity building and extension services for farmer groups and associations, Diesel and solar powered pumps were distributed for winter irrigation from a near wadi with shallow groundwater supported by a GW recharge subsurface dam
Pastoralism and grazing areas	• Degradation in natural environments, including forests and rangelands	• Improving rangeland and livestock production • Conserving forests and natural resources	

Sector	Potential impact	Suggested adaptation strategies	Aqua4Sudan implemented strategies
West Darfur			
Rural water supply	• Further depletion of groundwater resources • Infeasibility of harvesting surface water because of frequent dry spells	• Implementing new water projects (wells and dams) and rehabilitation of the existing water sources in the selected catchment areas • Suggesting new water harvesting techniques • Building capacity on water harvesting techniques • Carrying out additional studies and modeling in order to: - Predict changes in temperature, rainfall and evapotranspiration rates for West Darfur - Assess existing groundwater resources - Develop and implement IWRM plans at state and catchment levels	*In Sirba, Wadi Muhbas, wadi adar, wadi Jabal Moon, wadi sisi catchments, West Darfur:* **Water supply and GW Recharge:** 3 check dams, 5 sand dams, 4 subsurface dams, 81 hand pumps, 7 water yards and 15 mini water yards **IWRM Plans:** 5 community led IWRM plans were developed. Climate scenarios were incorporated in water resources assessments which informed the development of the IWRM plans
Smallholder farmers in rainfed irrigation	• Adverse impact on crop yield to be manifested in a decrease of production and productivity	• Improving agricultural production • Introducing drought resistant and early maturing varieties • Providing agricultural inputs	950 feddan of pasture was re-seeded, 2200 households received seeds, 4 mini irrigation schemes were implemented, 5 trainings in water harvesting techniques were carried out
Pastoralism and grazing areas	• Deterioration of rangelands and forest cover • Disappearance of some rangelands' species • Migration of wild animals	• Improving rangeland and livestock production • Conservating forests and natural resources	300 m2 was planted with trees
South Darfur			
Rural water supply	• Reduction in seasonal stream levels and groundwater levels • People displacement and conflict over the limited water resources	• Rehabilitating hafeers and dams would improve water access • Maintaining existing reservoirs and rehabilitation of the water infrastructure to increase water storage capacity • Building capacity on water harvesting techniques • Establishing rain gauge stations to monitor and provide hydrological information • Developing and implementing IWRM plans at states and catchments levels	*In wadi Nayal, Wadi Andur, Wadi Dumma and Wadi Tonkitir, South Darfur:* **Water supply and GW recharge:** 8 check dams, 14 sand dams, 5 subsurface dams, 24 hand pumps and 10 mini water yards **IWRM Plans:** 4 community led IWRM plans were developed Climate scenarios were incorporated in water resources assessments which informed the development of the IWRM plans

Sector	Potential impact	Suggested adaptation strategies	Aqua4Sudan implemented strategies
Smallholder farmers in rainfed irrigation	• Appearance of other invasive species • Decrease in production and productivity	• Addressing poor land management • Improving varieties for field and horticultural crops • Improving water harvesting • Improving spreading technologies, • Improving crop storage • Establishing community forests and nurseries • Legislating to improve community adaptation to climate change • Raising awareness among policy makers and government institutions	Training in 1- terracing techniques (theoretical and practical) 2- agricultural packages 3- vegetable cultivation methods for over 280 members (TOT) Improved seeds, tools and materials handed to 850 farmers
Pastoralism and grazing areas	• Threat to animal production • Deterioration of forestry cover • Disappearance of palatable rangeland species	• Mapping and monitoring of current condition of rangelands • Rehabilitating livestock markets • Replacing cattle with smaller livestock • Surveilling animal diseases regularly • Addressing overgrazing problem • Addressing problem of deforestation • Looking for alternative energy sources	

Box 1: Integrated Water Resources Management (IWRM)

The IWRM concept became popular after Dublin international conference on water and environment in 1992.* The conference spelled out the so called "Dublin principles," which were adopted later as IWRM principles. The main objective of IWRM is to manage all the available water and land resources in a coordinated, integrated and equitable way, to maximize the water's economic return and social welfare, taking into consideration the sustainability of water resources for the future generation. It looks at water resources beyond the classical way (namely, to manage each sector seperately) and promotes managing the basin's resources as one system. IWRM involves several disciplines, including but not limited to water and environmental sciences, social sciences, engineering, economy, and project management. These disciplines should be involved in water management activities to ensure the effectiveness of the proposed solutions.

* The Dublin Statement on Water and Sustainable Development, also known as the Dublin Principles, recognizes the increasing scarcity of water as a result of the different conflicting uses and overuses of water. See: https://www.wmo.int/pages/prog/hwrp/documents/english/icwedece.html.

Box 2: Towards sustainable and integrated management of non-Nilotic water resources in Sudan: IWRM for climate change adaptation and conflict reduction

Holistic approaches are essential to address water, environmental, and natural resources challenges through multiple lenses (i.e., socio-economic, political, technical, and ecological). Adopting the IWRM principles is one of the most successful ways manage the potential impacts of climate change - particularly the change in rainfall patterns - on water and food security. Those impacts are evident in rural areas without access to the Nile River. There people rely mainly on unimproved and unreliable water sources like seasonal streams or wadis and groundwater sources for subsistence. Especially in those areas there is an urgent need to adopt a holistic approach like IWRM. In addition, lobbying for IWRM to relevant government stakeholders at the state and catchment levels will contribute to long-lasting and cohesive water resource management. This approach can help avoid instability, increase mutual understanding and social cohesion among different water user groups with different ethnic backgrounds and livelihoods, promote peace in those areas, and enhance water use efficiency.*

* For more information about the role of IWRM as a recipe for peace keeping and conflict reduction, see: Corbijn, C., Hassan Mohamed Elamen, M. IWRM and Peace: The Contribution of the Integrated Water Resource Management Approach to Conflict Reduction and Peace – The Case of the Rural Water for Sudan Project. Aqua4Sudan Partnership, 2021.

8 GOOD CLIMATE ADAPTATION PRACTICES IMPLEMENTED BY AQUA4SUDAN PARTNERSHIP

In Sub-Saharan Africa, rainwater harvesting (RWH) and management in rainfed agricultural systems was found to be beneficial in a number of ways. It can improve the soil water content of the rooting zone by up to 30%, improve the crop yield by up to sixfold when RWH was combined with fertilizer use, reduce the risk of total crop failure from dry spells through supplemental irrigation of rainfed agriculture, improve water and crop productivity, increase the possibility of net profits, and allow smallholder farmers to diversify crops. Hence RWH can improve household food security, dietary status, and economic return (Biazin et al., 2012).

In Qala Aanhala catchment, the Aqua4Sudan partnership has implemented deep chiseling as a water conservation and harvesting technique, targeting 443 smalholder farmers. The results were very promising. The yield was found to increase by 250% in some areas. Similarly, the project implemented half-moon terracing techniques in Mahala catchment.

Niemeijer (1998) emphasized indigenous technologies (water harvesting system), as used on the piedmont plains of Kassala's border area, can represent ecologically sustainable farming systems. These technologies do not necessarily need to be complemented by external input, which is limited by factors such as labour and water availability.

RWH has also revealed to be a reasonable solution for water shortage in the semi-arid area of Al Qadarif city. Following the building of some small dams – originally built for seasonal flood control, these dams now provide multiple benefits, including 1) availability of groundwater resource all year long, 2) ability of the farmers to cultivate vegetables throughout the year, 3) supply of vegetables at affordable prices to the city markets, 4) increase of income and enhancement of the well-being of small farmers, and 5) ecological enhancement through the growth of trees in the reservoir area. The trees in turn became a refuge to local and migratory birds in the tree-cleared agricultural region and a dry-season recreation area for the city population (Ibrahim, 2009). There is a great potential in upscaling this model in other areas in Sudan.

9 RECOMMENDATIONS

Several measures would help increase future water security and reduce the potential impacts of changes in rainfall patterns:

- Target considerable reliable water resources, such as deeper groundwater and reduce dependence on shallow unimproved sources.
- Maintain the existing water sources to make them operational at the outset of drought periods.
- Put a system of water accounting in place to monitor and predict changes and additional stresses.
- Develop water resources management plans for targeted catchment areas.
- Promote IWRM with relevant government stakeholders at both the state and local levels, and share the lessons learned from other successful case studies with a wider community of practitioners working on IWRM and water conservation.
- Adopt community-based adaptation measures by involving the community in the construction, operation and maintenance of the water sources.
- Investigate and promote appropriate methods for household water treatment locally.
- Renovate the existing and construct additional appropriate infrastructure to provide water for livestock to reduce the possible tension resulting from the competition between pastoralists and farmers.
- Rehabilitate pastoral livelihoods through approaches to sustainable (environmental, social, and economic) management of land and livestock resources that promotes successful coexistence between users.
- Establish proper monitoring systems for rainfall and water level/discharge in ungauged catchments and facilitate access to available meteorological and hydrological information.
- Enhance institutional support, research and information transfer in order to improve the risk management by farmers.
- Demonstrate and promote water conservation techniques for agriculture in order to reduce the vulnerability of agriculture to rainfall variability.

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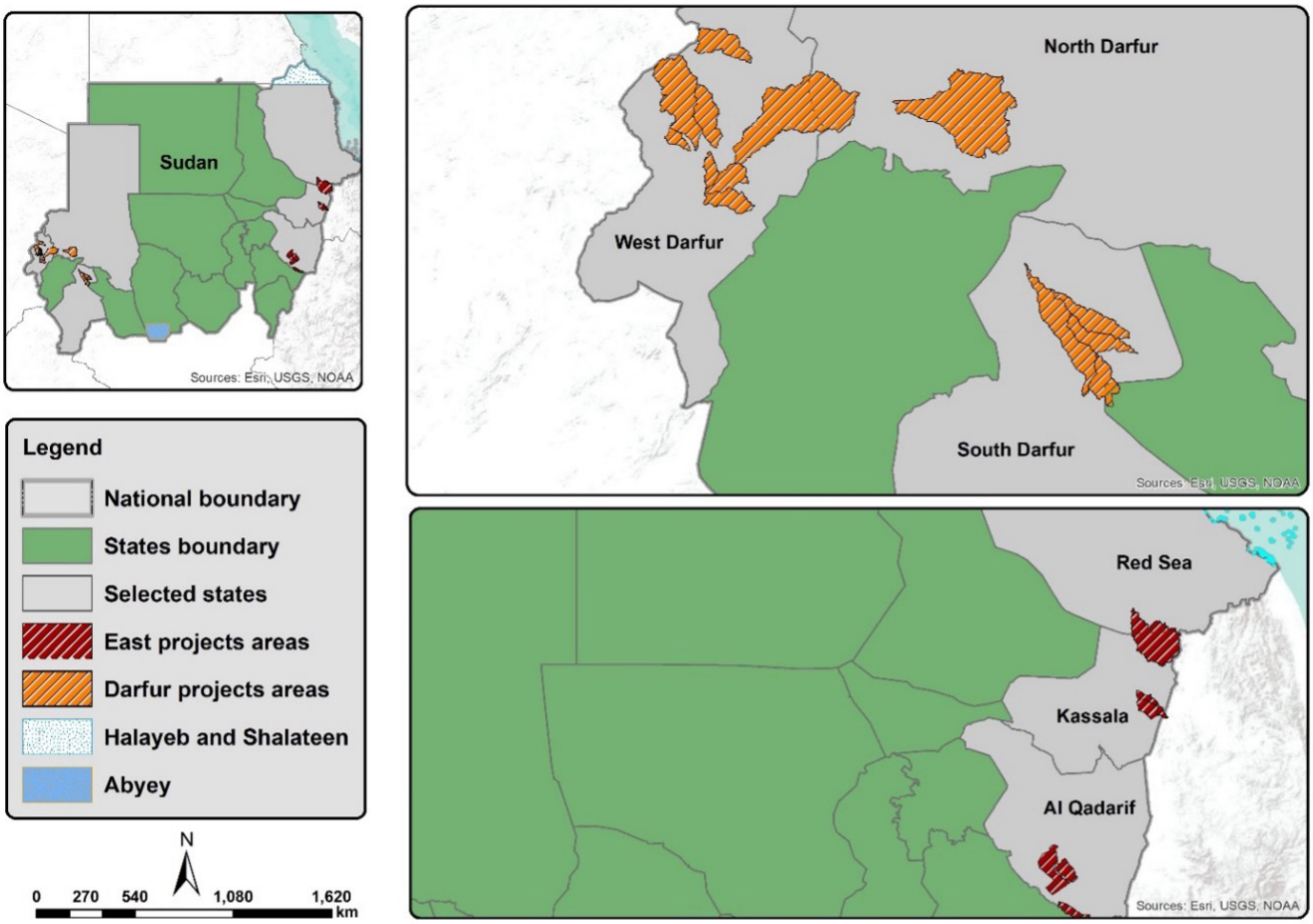

Figure A1. Aqua4Sudan partnership project areas

Table A1 An overview of the catchments per state in which the Aqua4Sudan partnership carried out IWRM projects

State		Project location
Eastern States	Red Sea	Hamesh Koreib catchment
	Kassala	Tahaday catchment Adurut catchment Hamesh Koreib catchment
	Al Qadarif	Wadwadyda catchment Banigui catchment Gala Alnahal catchment
Darfur states	North Darfur	Wadi Muhbas catchment Wadi Bargo catchment
	West Darfur	Wadi Darram catchment Wadi Gabalmoon catchment Wadi Gallal catchment Wadi Muhbas catchment Wadi Burie catchment Wadi Sisi catchment Wadi Sirba catchment Wadi Adar catchment
	South Darfur	Wadi Duma catchment Wadi TonKitir catchment Wadi Andur catchment Wadi Nyala catchment

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