A Rapid Environmental Assessment of

SUDD WETLAND ECOSYSTEM

in South Sudan

UN environment programme

1972-2022

gef 30 years

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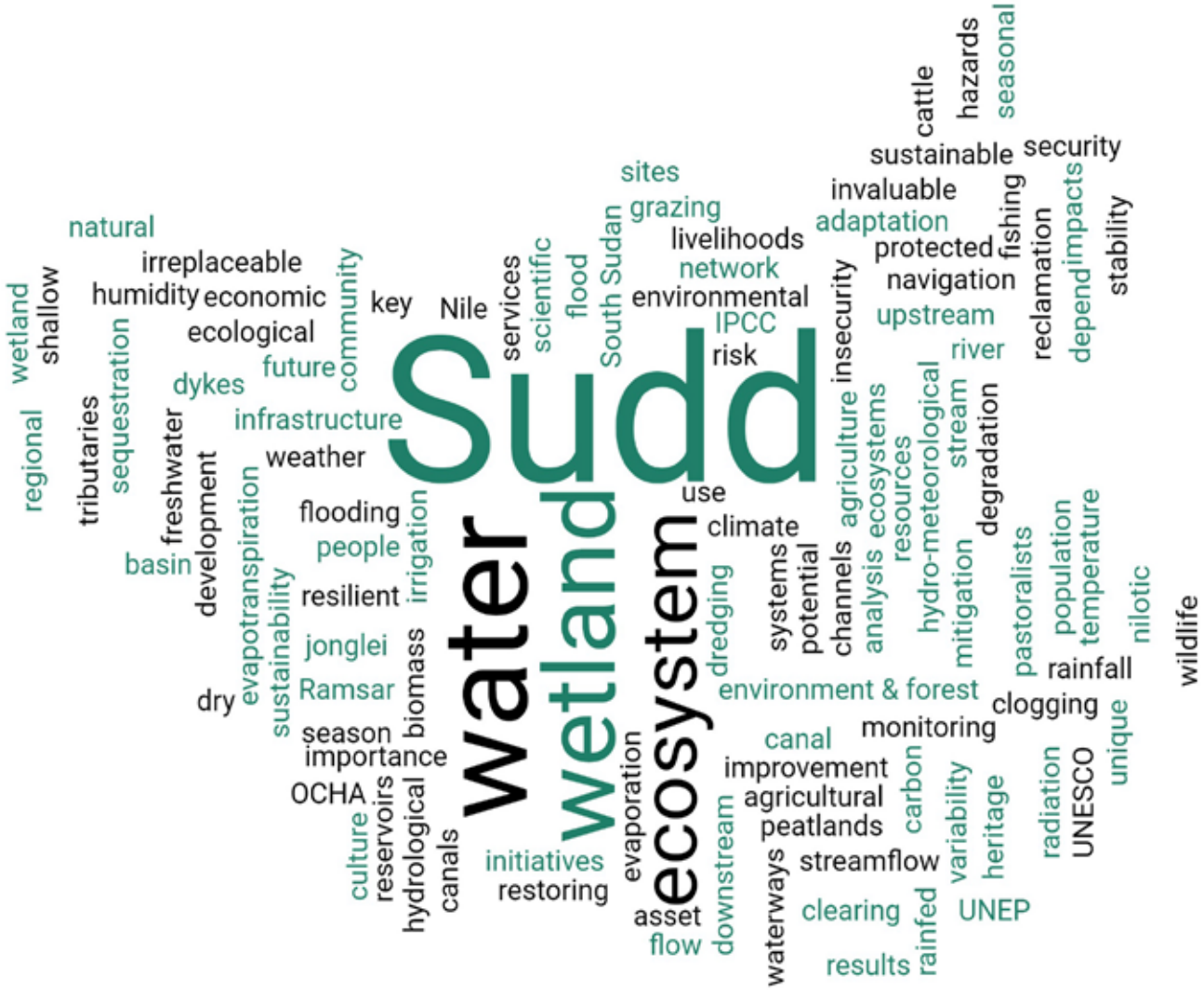

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A barge in one of the waterways in the Sudd
Photo credit: *Michael Lopidia*

Foreword

The Sudd wetland is one of the largest freshwater ecosystems in the world and a designated Ramsar site. It covers an area of 57,000 km^2 which varies with the seasons and the extent of the Nile flooding. The wetland is a habitat to a wide array of biodiversity and plays an important hydro-ecological role in South Sudan and the wider River Nile Basin region. As an oasis amid the surrounding dry Sahelian landscape, the wetland attracts migrating animals and supports the winter migration of birds. About one million people depend on its natural resources for their livelihoods and wellbeing. One of the greatest values of the Sudd is that it supports unique and irreplaceable cultures like the Dinka, Nuer, and Shilluk.

The Sudd wetland is an environmental and economic asset that supports livelihoods, the national economy, and ecosystem services including climate change mitigation and hydrological functions in the bigger Nile Basin area. Non-economic values include its role in supporting the culture, unique wildlife and as a symbol of national identity for South Sudan. The total economic value of the Sudd wetland in 2015 was estimated at about US $3.3 billion. However, human activities are some of the main driving forces behind environmental change and degradation in the Sudd wetland. These include insecurity, geopolitics and changes to the hydro-meteorological regime, climate change and human-led land use change.

The Government of South Sudan has shown great political support towards addressing issues of environmental and natural resources management by signing up to and implementing global policies. However, implementation is challenged due to conflict coupled with the remoteness of the Sudd wetland which have led to a lack of scientific information. Attempts to rebuild institutions have been slow but are developing and evolving. The Ministry of Environment and Forestry and the Ministry of Wildlife Conservation and Tourism, and the Ministry of Water resources and Irrigation are working in tandem with sectors and development partners to develop policy and regulatory frameworks and to ensure responsible protected area management within this region. Further challenges arise from human factors such as poverty, geopolitics of the River Nile basin, and natural factors such as climate change.

This rapid environmental assessment is an attempt to provide information which can then be used to underpin the various management plans and strategies that the government needs to drive the ecological, hydrological, agricultural, and other social developmental needs for the Sudd wetland.

It is hoped that this rapid environmental assessment will support the development of the supervisory, managerial, and regulatory capacity for the entire Sudd wetland system.

I wish you good reading.

Hon. Josephine Napwon Cosmas

Minister of Environment and Forestry
Government of South Sudan

Preface

This rapid assessment has reviewed the state of environment in the Sudd wetlands. It covers aspects such as biodiversity, forests, wildlife, agriculture, climate change, rural development, wetland, and water resources. Given that much of the land cover in this area is dry, semi-arid grassland and shrub land, the water resources of the Sudd provide a valuable lifeline to the people, and to the animals and plants that inhabit it. In 2015, the annual value of the Sudd for water regulation and for water supply alone, was estimated at US $1.12 billion. These numbers highlight areas for potential investment, and flag areas that may require protection, and the advantages or disadvantages of developments. Some of the lucrative sectors include fishing, industry, irrigation agriculture, energy production, and livestock development.

People are increasingly exploiting the Sudd wetlands resulting in widespread degradation. Furthermore, there is much political, economic, and social interest in developing this area underscoring the need for a better understanding of the risks of doing so.

This report provides a credible assessment based on the most up to date scientific information and analysed by experts. However, there are still many unknowns and gaps in the data; and some of the data is outdated. Data is the foundation to providing credible evidence and confidence to different policy and environmental decisions that may be made in support of government programmes. To that end, studies (such as on the hydrology of the Sudd) must be explored further to create the scientific foundation for any planned infrastructure developments in this area.

As highlighted in the report, Strategic Environmental Assessment (SEA), Environmental and Social Impact Assessments (ESIA) are indispensable tools that could be used to understand the risks of development. By considering impacts to livelihoods, security issues, population displacement and degradation of ecosystem services, among others, it would be able to identify, predict and assess the potential impacts on the wetland ecosystem associated with any development and thus mitigate them. Ultimately this would encourage the wise use of the resources of the Sudd wetland in alignment with the requirements of the Government of South Sudan and the international community under the multilateral Environmental Agreements (MEAs).

Hon. Joseph Africano Bartel

Undersecretary for Environment,
Ministry of Environment and Forestry
Government of South Sudan

Acknowledgments

Production and Editorial Teams

UN Environment Programme

Charles Sebukeera, Regional Science - Policy Coordinator, UNEP Africa Office

Nicholas Mutiso, Project Coordinator, South Sudan GEF6 Cross-Cutting Capacity Development (CCCD) project, UNEP Africa Office

Environmental Pulse Institute

Ashbindu Singh PhD, Project Coordinator

Peter Gilruth PhD, Senior Advisor

H. Gyde Lund, Lead Researcher

Elizabeth Kironde, Researcher and Writer

Eugene Apindi Ochieng, GIS and Data Visualisation

Joselyn Mutegeki, Researcher

Reviewers

Hon. Joseph Africano Bartel, Undersecretary for Environment, MoEF

Paul Lado Demetry Jubek, Ag. Director for Biodiversity, CBD National Focal Point,

CCCD Project Liaison Officer , MoEF

Payai John Manyok, D/D for Climate Change and UNFCCC Focal Point

Dorina Keji Zakariah Gubek, Ag. DG for Environmental Education and Information, MoEF

Contributors

Hon. Joseph Africano Bartel

Hon. Jaden Tongun Emilio Wani

Hon. Theresa Cirisio Iro

Hon. Hellen Ngaidok Lokurnyang Lado

Prof. Andrew Lexston Athiba

Prof. Aggrey Lemi Abate

Prof. John Gowdy

Assoc. Prof. Dr. John Leju Celestino Ladu

Dr. Khalid R. Marol

Dr. Bojoi Moses Tomor

Thon Wuor Awol

Hellen Achia Jackson Lino

Khamis Nicholas Ramba Alex

Elizabeth Fredrick Iwi Aliko

David Peter Mina
Regina Ossa Lullo
Michaya gamunde Nasona
David Batali Oliver Samson
David Chan Thiong Dhol
Patrick Taban Abdullai Waran
Lutana Musa Lasu
John Ater Maker Dhalbeny
Dorina Keji Zakariah Gubek
Paul Lado Demetry Jubek
Idro Mark Dradi Duku
Wani Nelson Amos Mogga
Erineo Huku Ochalla
Emmanuel Raduba
Justin Taban
Michael Mondi Lopidia Duku
Lwanga Tiba Charles Waya
Timothy Thwol Onak Yor
Kenyi Bullen Nathaniel Baggu
Melania Peter Ajang Nybong
Dut Jacob Daw Dut
George Louis Tokporo Tadu
Lona Nalurit Darius Gore
Thomas Jada James Jacob
Lazarus Pierentino Lugoi
Moses Kot Bol Ngong
Mojwok Ogeith Obul
Nhial Tiitmamer kur
Mary Benjamin Loki
Payai Manyok John

Acronyms

Acronym	Meaning
AF	Adaptation Fund
AW	Alluring World
CBD	Convention on Biological Diversity
CCCD	Cross Cutting Capacity Development, right
CH4	Methane
CIF	Climate Investment Fund
CMIP5	Coupled Model Intercomparison Project Phase 5
CORDEX	Coordinated Regional Climate Downscaling Experiment
CTF	Clean Technology Fund
ESA	European Space Agency
ESIA	Environmental and Social Impact Assessment
EWS	Early Warning System
FAO	Food and Agriculture Organization of the United Nations
FEW NET	Famine early warning systems network
FoA	Fortune of Africa
GCF	Green Climate Fund
GEF	Global Environment Facility
GHG	Greenhouse Gas
GIEWS	Global information and early warning system
GoSS	Government of South Sudan
GPI	Global Peatlands Initiative
GWL	Global Warming Level
IPCC	Intergovernmental Panel on Climate Change
LULCC	Land Use Land Cover Change
MEA	Millennium Ecosystems Assessment
MoE	Ministry of Environment
MoEF	Ministry of Environment and Forestry
MoP	Ministry of Petroleum
MP	Market-purchased
n.d.	Not dated
NASA	National Aeronautical and Space Agency
NBI	Nile Basin Initiative
NDC	Nationally Determined Contributions
NH3	Ammonia
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OP	Own produced
PET	Potential Evapotranspiration
REDD	Reducing Emissions from Deforestation and Forest Degradation
SAFER	Sustainable Agriculture for Economic Resiliency
SEA	Sudd Environment Agency
SPLA	Sudan People's Liberation Army
SSNCO	South Sudan Nature Conservation Organisation
TEV	Total Economic Value
TROPOMI	TROPOspheric Monitoring Instrument
UN	United Nations
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
VCM	Voluntary Carbon Market
WCMC	World Conservation Monitoring Centre
WCS	Wildlife Conservation Society

Executive Summary

The Sudd wetland is a designated Ramsar site. It has an estimated area of 57,000 km^2 and is one of the largest freshwater ecosystems in the world. The Sudd is an environmental and economic asset that supports livelihoods, the national economy, and ecosystem services including climate change mitigation and hydrological functions in the bigger Nile Basin area. It also has non-economic values including its role in supporting the culture, unique wildlife and as a symbol of national identity for South Sudan. One of the greatest values of the Sudd is that it supports unique and irreplaceable cultures like the Dinka, Nuer, and Shilluk. Draining the Sudd would destroy these cultures.

One of the objectives of this rapid environmental assessment is to provide information to underpin the various management plans (ecological, hydrological, agricultural, and developmental) that the Government of South Sudan (GoSS) should implement to ensure that the development of the Sudd wetland is sustainable. In this context, the following key recommendations are made to the GoSS and its partner agencies.

Key recommendations

- **Implement obligations under the Ramsar Convention.**
- **Employ a Resilient Management Strategy combining action, science, and learning from best practice in the Sudd:** Given the value of the natural resources and their contribution to ecosystem health and human wellbeing such as the pastoralists, livestock and other benefits accrued from the Sudd wetland, the GoSS should promote policies that maintain the healthy functioning of the Sudd wetland by protecting and restoring the goods and services they provide. Such policies might include designating additional protected area status, for example, the suggested UNESCO World Heritage Site listing. Implementing this recommendation would require resilient management strategies that can adapt to shifting geo-politics, changes in water demand and the impacts of climate change.
- **Carry out Environmental and Social Impact Assessments (ESIA) of infrastructure projects:** The requirements under the Ramsar Convention stipulate that the government does everything in its power to maintain the integrity of the Sudd ecosystem. Rigorous environmental and social impact assessments based on credible scientific information should be conducted before embarking upon infrastructure projects. Such ESIAs should consider impacts to livelihoods, security issues, population displacement and degradation of ecosystem services, among others.
- **Examine the policies, practices and impacts of the possible revival of the Jonglei Canal:** This recommendation should be based on the results of an ESIA with rigorous scientific data collection and analysis. If pursued, GoSS should adhere to the core principle of '*water for South Sudanese people and ecosystems first*' before releasing excess water to downstream countries. There is also need to mitigate flood intensity by negotiating with the upstream riparian countries.

  Water management in South Sudan should account for the following issues:

  - Water for ecosystem services
  - Water for electricity generation
  - Water for irrigation
  - Management of excess water to reduce flooding.

- **Deploy an early warning system for flood and drought:** According to recent IPCC scenarios, more seasonal flooding and drought are likely to occur in the region in future. Early warning systems (EWS) are key elements of climate change adaptation and disaster risk reduction to avoid or reduce the damages caused from such hazards. To that end, GoSS should strengthen capacity for drought and flood Early Warning Systems through an improved hydro-meteorological monitoring network and timely communication to community level. There is opportunity to leverage ongoing initiatives like the USAID Famine Early Warning Systems Network (FEWS NET), FAO Global information and early warning system (GIEWS), and the OCHA Anticipatory Humanitarian Action framework, among others.

  Strengthening of the hydro-meteorological system should include, among others, Automatic Weather Station, Cup Counter Anemometer,

Pyranometer for Shortwave and global Radiation, Rain Gauge, Rainfall Recorder and Logger, Standard Weather Station, Stream gauges, Evaporation Recorder, Wind Vane and Temperature Humidity Recorders. Capacity building for these equipment will also be required.

The GoSS should negotiate and enter bilateral agreements for sharing hydro-meteorological information with upstream countries of the Nile River such as Uganda.

- **Improving flood control measures and recovering local economies:** The buildup of biomass in the Sudd and along the White Nile has been clogging the waterways and disbursing the water across all the tributaries and their surrounding area. Flood control measures, like dykes, dredging, removal of biomass for clearing water channels, small canals and irrigation channels, reclamation of land, should be considered to support local fishing and agriculture. Dredging will not only help the streamflow, but also improve water navigation. Areas suitable for deep water or shallow water dredging should be identified after ESIAs. Agriculture production in rainfed areas could be improved by implementing the proposed Irrigation Master plan of 2015.
- **Reduce uncertainties by promoting scientific research:** The Sudd wetland has not attracted the attention of the global research community due to conflict and its remote location in South Sudan. As indicated in sections of this report, there are many research areas that require attention. These include spatial extent and variability of the Sudd, water availability, evapotranspiration rate, impacts of climate change, impact of Sudd on regional climate, extent of peatlands, carbon sequestration potential, cultural and ecosystem dynamics. The GoSS, together with development partners such as UNEP, should endeavor to put the Sudd on the global research agenda. Results would be important for national level decisions on the wise use of the Sudd wetland ecosystem for the future security, sustainability, and stability of South Sudan.

Doum (Hyphaene thebaica) plants in the Sudd
Photo credit: *Michael Lopidia, WCS*

1. Introduction

Background and objectives of this report

South Sudan, located in Eastern Africa, is bordered by the six countries of Central African Republic, Democratic Republic of the Congo, Ethiopia, Kenya, Sudan, and Uganda. The country has a range of ecosystems including tropical forest, swamps, and grassland. The White Nile (known as Bahr el Jebel between Nimule and Lake No) traverses the country, passing by towns including Juba, Bor and Malakal.

The Sudd wetland, found in the lower reaches of Bahr el Jebel in South Sudan has an area of about 57,000 km² (Figure 1), or slightly over 8 per cent of the country (ESA, 2021). It is one of the largest freshwater ecosystems in the world, habitat to a wide array of biodiversity and plays an important hydroecological role in South Sudan and the wider River Nile Basin region.

The Sudd is a natural resources asset. However, the historical situation of South Sudan severely impacted the development and conservation efforts in the area. There is now the opportunity for South Sudan to overcome this handicap and develop unique environmental policies to foster the sustainable development and utilization of the resources of the Sudd wetland as part of the country's bigger environmental governance agenda. If well managed, the result could be greater support to livelihoods, the national economy, ecosystem services including climate change mitigation and its hydrological function in the bigger Nile Basin area, and as a symbol of national pride supporting cultures and traditions unique to South Sudan.

Against that background, the objective of this rapid assessment is to analyze and document historical and current environmental challenges and options for the conservation and restoration of the Sudd wetland. It will also highlight the associated risks of

Figure 1: *Location map of South Sudan (MoEF, 2021)*

Disclaimer: The boundaries and names shown, and the designations used on this map do not imply official endorsement or acceptance by the United Nations. The final boundary between the Republic of South Sudan and the Republic of Sudan has not yet been determined. The final status of Abyei area is not yet determined.

mismanagement and the benefits of conservation to people, nature, economies, and thus ultimately support the achievement of the Sustainable Development Goals.

The Sudd wetland: An overview

The areal extent of the Sudd wetland is strongly linked to the seasons and changes from year to year, ranging from a high of 90,000 Km^2 in the wet season to a low of 42,000 Km^2 in the dry season depending on the high seasonal flood (UNESCO, 2017). The wetland is sustained by the flow of the White Nile from Lake Victoria in Uganda, in addition to surface runoff from its surrounding areas. The White Nile flows northwards from Juba across a shallow depression to produce a network of waterways, lagoons and swampy areas, underlain by nutrient rich, clayey soils.

The largest areas of the Sudd are found along the Bahr el Ghazal, where the Bahr el Jebel and Bahr el Zeraf rivers in the Upper Nile and Jonglei come together. The southernmost limit of the permanent wetland in the Sudd is Bor town, which is also the wettest.

Flooding strongly influences the Sudd's vegetation, which consists primarily of permanent swamps, river and rain-flooded grasslands (*toiche*), and floodplain woodlands. The land cover in the Sudd wetland area includes open waters, submerged vegetation, floating fringe vegetation, seasonally inundated woodlands, grasslands and scrubland (Figure 2 and Figure 3). The Sudd wetland is internationally recognized for its unique ecological attributes that include various endangered mammalian species, antelope migrations, large fish and Palearctic migratory bird populations. The Sudd and the Saharan flooded grassland ecosystem support two of the largest ungulate migrations in the world, those of the Tiang and White-eared kob (UNESCO, 2017); (MoEF, 2019).

The Sudd: A Ramsar site and wetland of international importance

The Convention on Wetlands (also known as the Ramsar Convention on Wetlands of International Importance Especially as Waterfowl Habitat) is a global inter-governmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. A key commitment by the Parties to the Convention is to identify and place suitable wetlands onto the List of Wetlands of International Importance, also known as the Ramsar List. The Sudd was designated as Ramsar site in 2006. The area of the Sudd wetland Designated Ramsar contains the permanent swamps that extends from Bor to Lake No (UNESCO, 2017).

A section of the Sudd wetland
Photo credit: *Michael Lopidia, WCS*

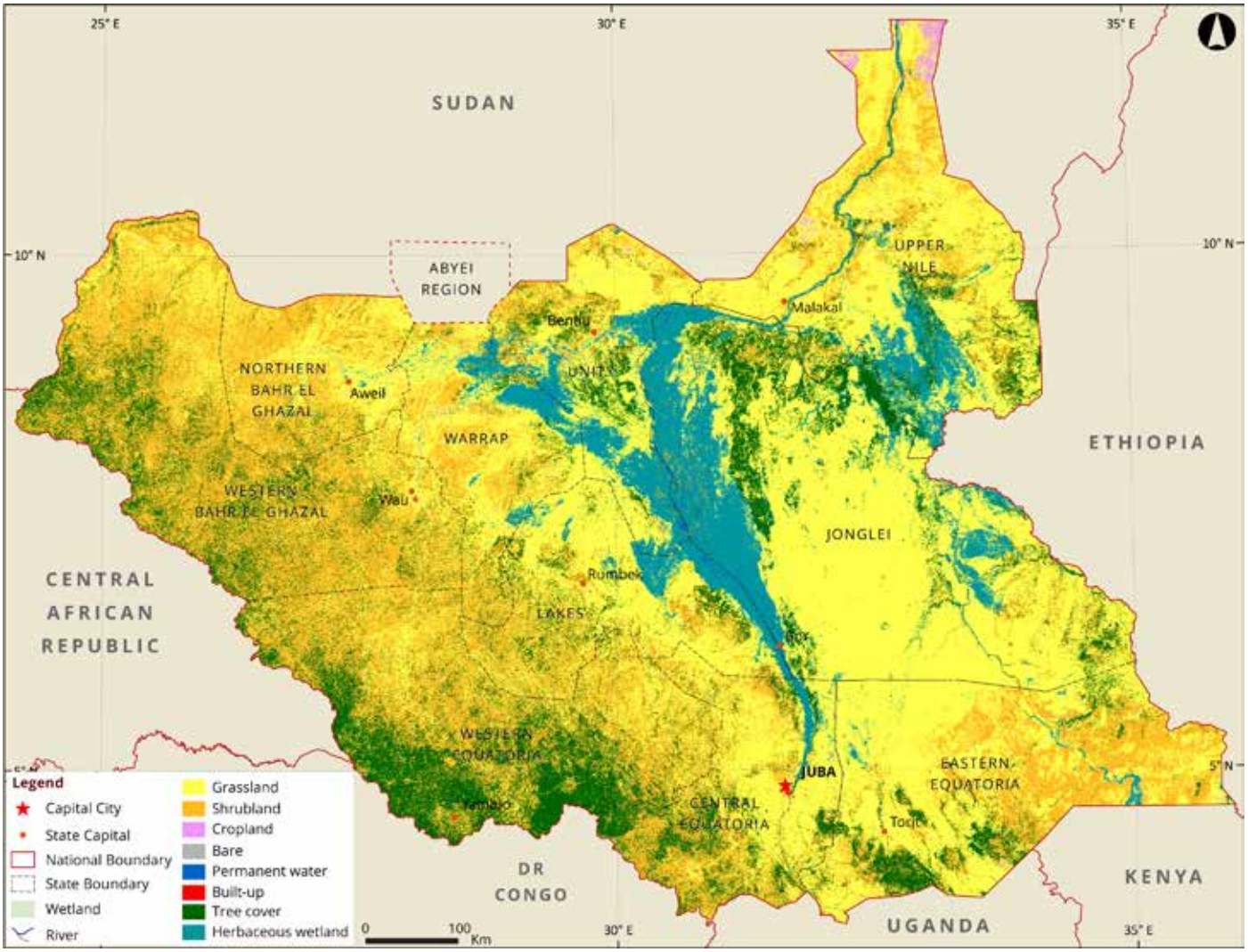


Figure 2: *South Sudan Land Cover 2020 (ESA, 2021)*

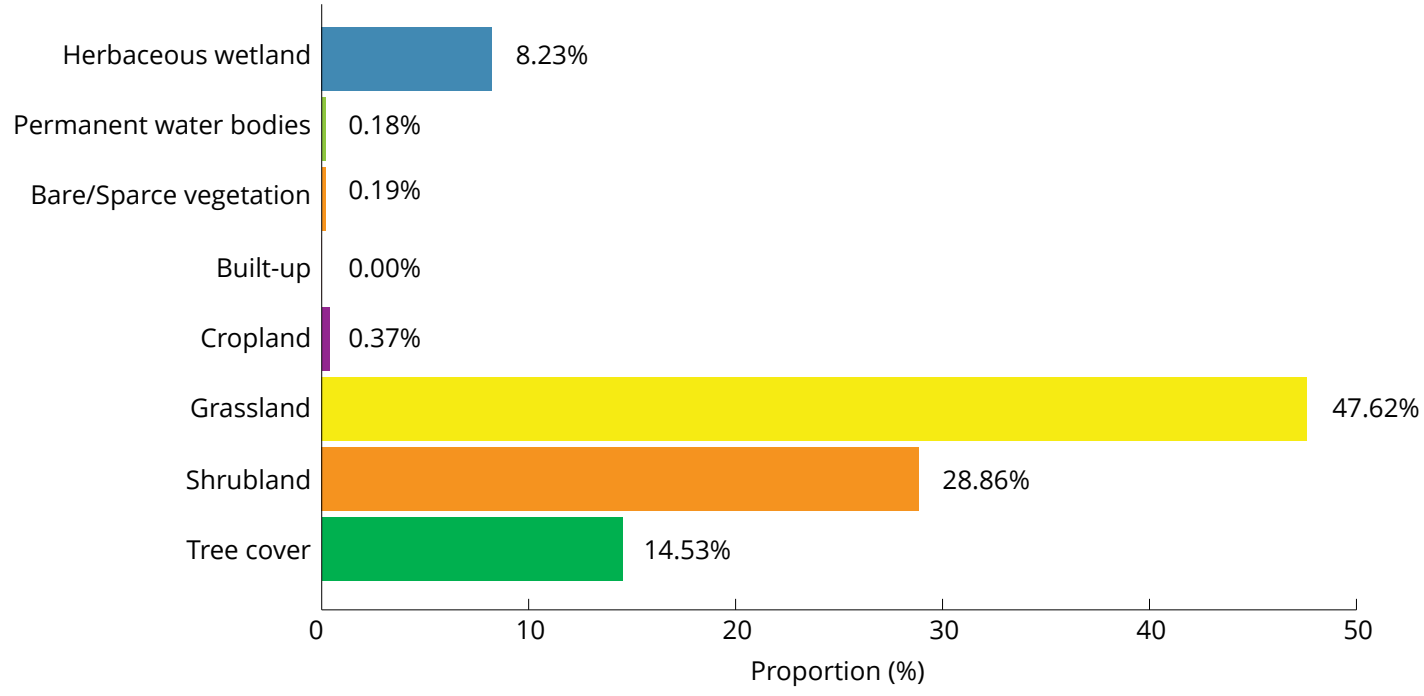


Figure 3: *Land cover distribution in South Sudan (ESA, 2021)*

2. Natural Resources of Sudd

Biodiversity

Systematic aerial surveys and reconnaissance of the Sudd wetland region conducted between 2007 and 2013 found that the Sudd wetland has large tracts of largely undisturbed and intact habitats. These habitats support significant viable flora and fauna as discussed below.

Flora

In the Sudd, usually the deep open water is surrounded by a permanent swamp zone consisting of *Cyperus papyrus*, *Vossia cuspidata* and *Typha* spp. which are important habitats for the endangered Shoebill stork. This in turn is surrounded by seasonally flooded grasslands consisting of *Echinochloa stagnina*, *E. pyramidalis*, and *Oryza longistaminata* as well as *Hyparrhenia ruffa* at the edge of the wetland (Riak, 2003). Unlike other wetlands, the Sudd wetland has not been shown to be a hotspot of plant species endemism. Out of the 350 plant species identified in the Sudd region, only one species is endemic, *Suddia sagitifolia*. *Suddia*, a rare genus belonging to the *Poaceae* family, is only known to exist in the Sudd Region.

Fauna

The Sudd is internationally recognized for its unique ecological attributes that include habitat for large mammalian species (some of which are endangered), antelope migrations, large fish populations and migratory Palearctic birds.

Mammals

The African elephant (*Loxodonta africana*), African buffalo (*Syncerus caffer*), Hippopotamus (*Hippopotamus amphibious*), and Sitatunga (T*ragelaphus spekii*). It hosts the world's largest concentration of endemic Nile lechwe (*Kobus megaceros*) – about 11,000 animals. The wetland is an oasis in the midst of a dry Sahelian landscape and as such attracts migrating animals, especially antelopes such as the Tiang (*Damaliscus lunatus tiang*), White-eared kob (*Kobus kob thomasi*) and the Reed buck (*Redunca sp.*) as shown in Figure 4 (FoA, 2021).

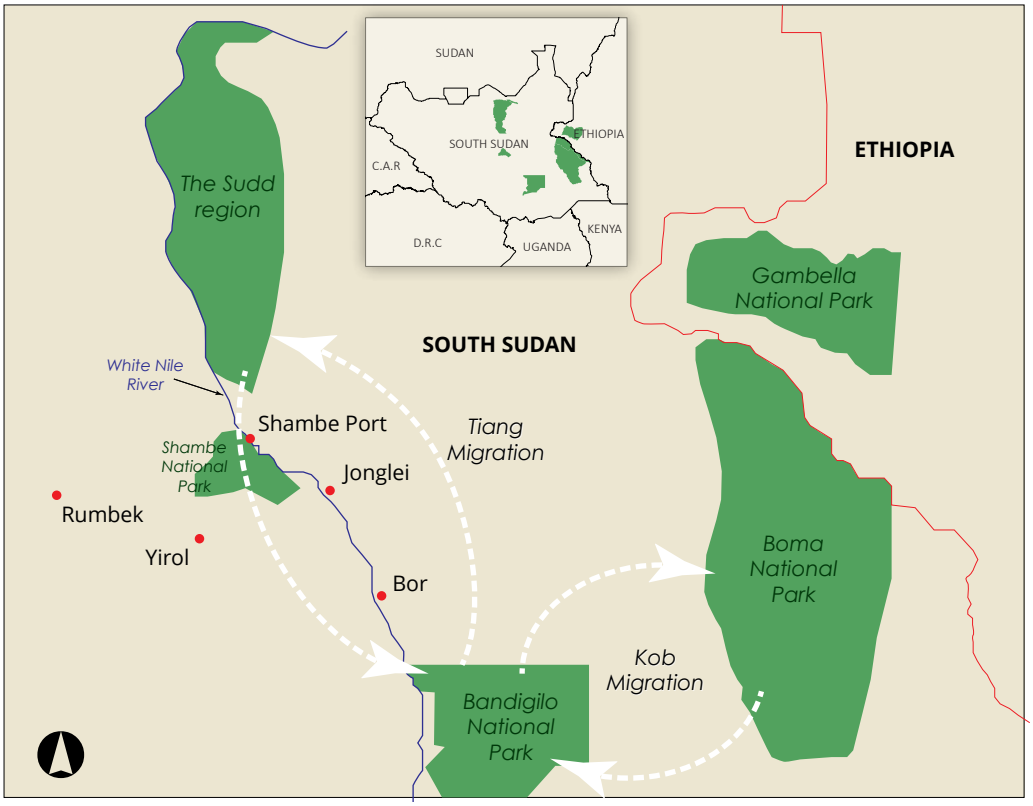


Figure 4: *Migration routes of the White-eared Kob (Kobus kob leucotis) and Tiang (Damaliscus lunatus tiang) (NBI, 2020)*

Aerial image of white-eared kob (Kobus kob leucotis) leaping across the grasslands of Southern Sudan. The Sudd wetland supports their annual migration.
Photo credit: *Aual Elkan and J. Michael Fay, Wildlife Conservation Society/flickr*

Birds

The Sudd supports the winter migrations of birds such as the Black Crowned Crane (*Balearica pavonina*), White Stork (*Ciconia ciconia*), Great White Pelican (*Pelecanus onocrotalus*), and the Black Tern (*Chlidonias niger*). It is part of the East Asian-East African flyway of Palearctic birds, that breed in Asia and Central-Europe but fly south to escape the winters. It is also a dry season refuge for birds that migrate within the African continent (UNESCO, 2017). About 7,000 Shoebill stork (*Balaeniceps rex*) occur in the Sudd wetland, which is a large proportion of the global population (UNESCO, 2017).

Fish

The range of aquatic habitats – open water, riverine, lacustrine and palustrine wetlands offer ideal habitat for breeding, feeding and growth for huge numbers of fish. Human interference has been minimal to date, leaving these habitats largely intact. Some fish species found include 31 Siluroids, 16 Characoids, 14 Cyprinoids, 11 Momyrids, 8 Cichlids, and 7 Cyprinodonotids and 8 endemic Nile dwarf fish (UNESCO, 2017).

Other

Not much has been published about the diversity of amphibians and reptiles, however it is thought that the size and remoteness of the Sudd has contributed to it having the largest crocodile population in the world (Riak, 2003).

Protected areas

South Sudan has 18 gazetted protected areas (six National Parks and 12 Game Reserves) covering 87,030 km^2 (13 per cent of the land area) as shown in Figure 5 (UNEP-WCMC, 2022). The key indicators of the protected areas in the Sudd wetland area are summarized in Table 1.

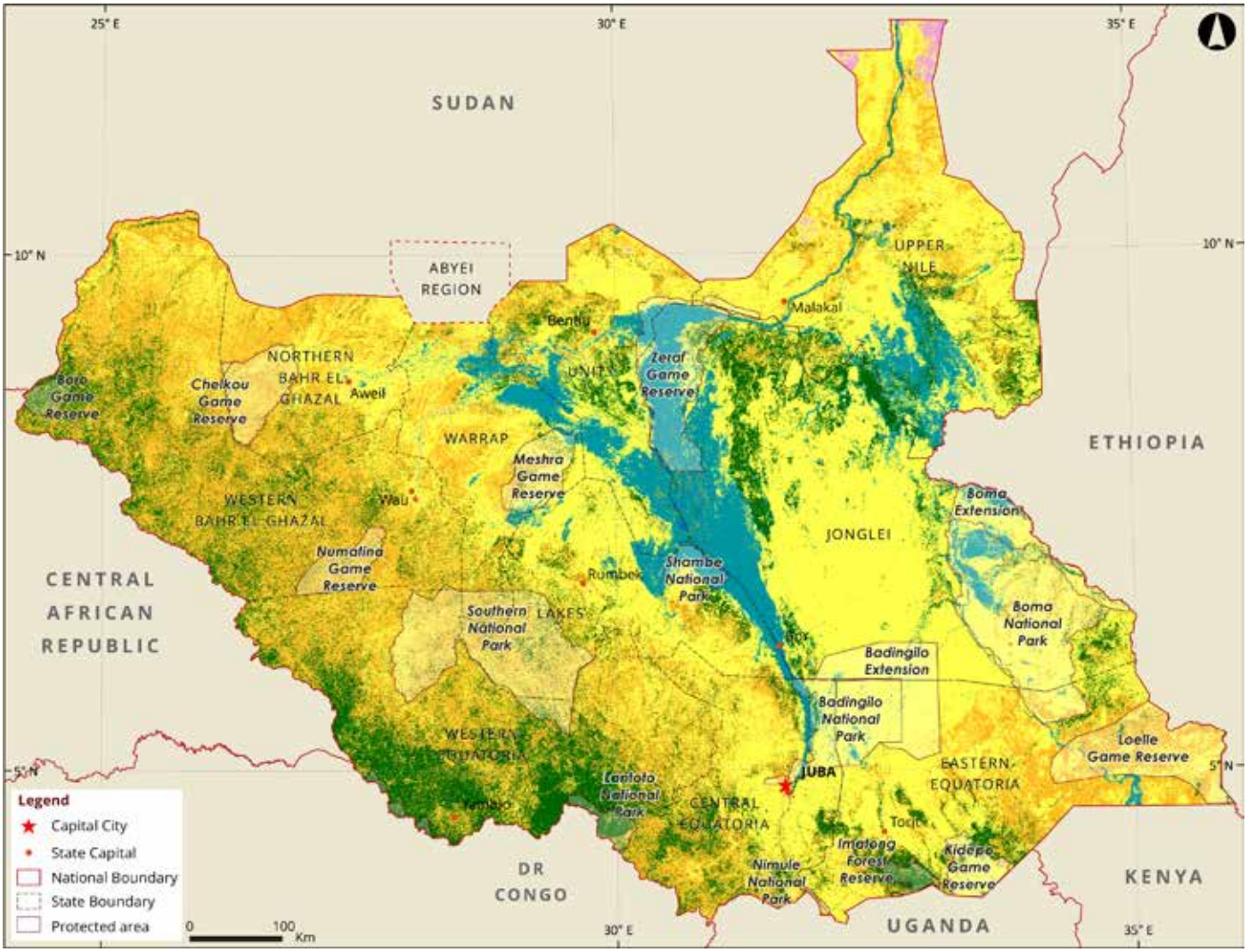


Figure 5: *South Sudan protected areas (Darbyshire, 2021).*

Table 1: *Protected areas in the Sudd wetland area (MoEF, 2019)*

Name	Year created		Area (km²)	Habitat
Bandingilo National Park	1986	For the protection of migratory antelopes and other sedentary species	16,500 (with the proposed extension the area is > 18,000)	Woodland savanna, grassland and flood plains
Shambe National Park	1985	For the preservation and protection of endangered northern race of the white rhino (*Ceratotherium simum cottoni*),	620	Woodland & wooded savanna, grassland, and flood plains
Zeraf Game Reserve	1939	Traditional hunting reserve for the Nile lechwe, buffaloes, giraffes, hippos, crocodiles, birds, etc.	8,000	Wetlands, Toich grassland, wooded savanna and floodplains
Fanyikang Game Reserve	1939	Traditional hunting reserve for the Nile Lechwe, hippos, Crocodile, birds, etc.	480	Wetlands, Toich grassland, wooded savanna and floodplains

Human dimensions of the Sudd

The People

The Sudd region is home to about 1 million people who depend on the natural resources for their livelihoods and wellbeing. The main tribes include the Dinka, Nuer, Bari, Mundari and the Shilluk (Figure 6). These are all indigenous Nilotes and well adapted to the seasonally flooded conditions in the Sudd. Livelihoods include fishing, nomadic agro-pastoralism, and collection of non-timber forest products. The people live on floating islands of vegetation and utilize traditional livestock management, hunting, and fishing techniques. The cultures and traditions are well suited to the local environment. For instance, the Shilluk tribe believe that killing the Nile lechwe is taboo making them a key factor in the conservation of that animal. These cultural and religious beliefs are an important contributor to sustainable environment management. It is important to understand and preserve these knowledge and practices as they are integral to the survival and livelihoods and the sustainable use of natural resources in the Sudd (UNESCO, 2017).

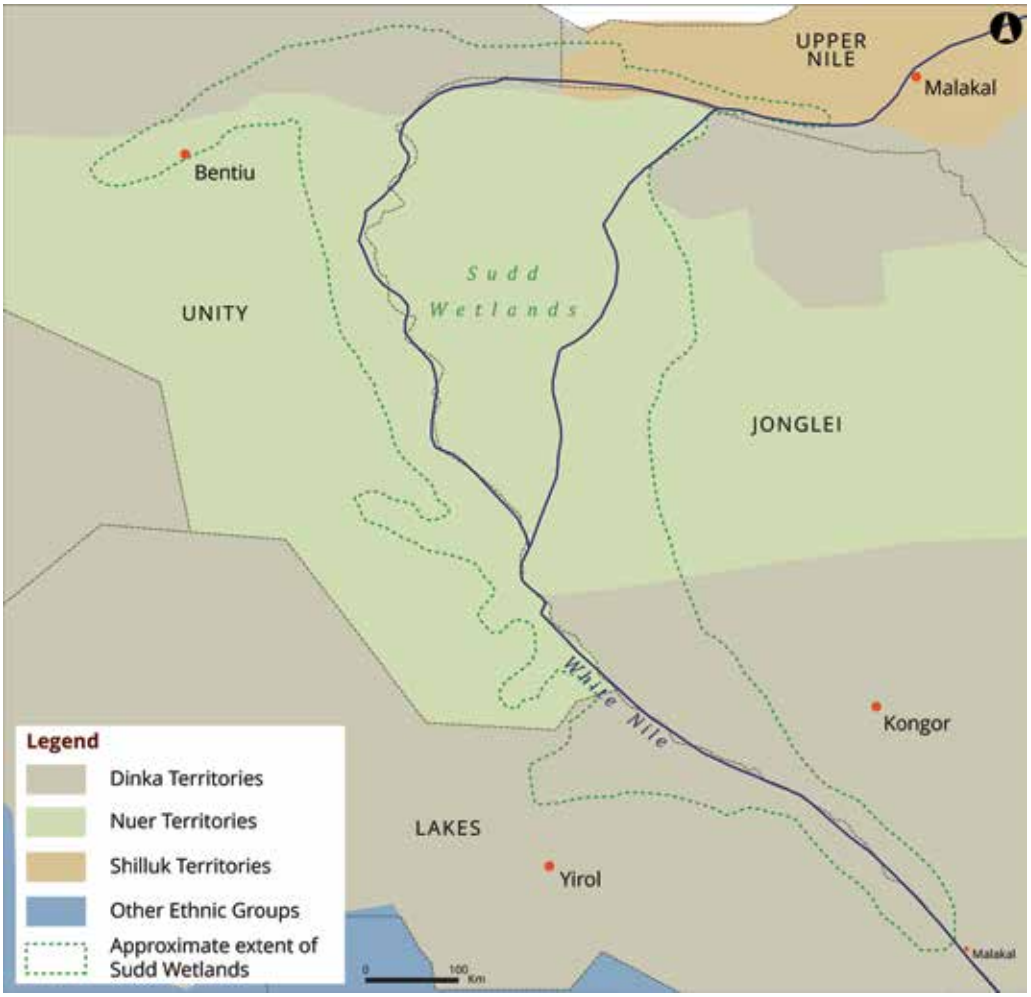


Figure 6: *The territorial boundaries of the three main indigenous pastoral groups inhabiting the protected areas of the Sudd wetland including the Dinka (brown), Nuer (green), and Shilluk (orange) (Ruuskanen, 2021)*

Characteristics of the Sudd Livelihood Zone

Livelihood zoning brings together environmental and human factors in a way designed to establish how households access income and food and provides forecasting of factors that may lead to food insecurity. By so doing, it provides those in decision making positions with a system of predicting the early signs of famine (FEWS NET, 2018).

The Sudd livelihood zone is a narrow swampy band of flood plain on either side of the River Nile running from north to south (Figure 7). Grasses such as papyrus and bush scrub are common. The soil along the riverbanks is clayey turning to sandy loam as one moves away from the river. Rainfall ranges between 700 and 1,300 mm per year falling in one season from May to October (FEWS NET, 2018). The mix of livelihood strategies employed in this zone include cropping, livestock farming, fishing, harvesting of wild products and other river-related activities.

Many households practice some form of rain-fed agriculture with sorghum being the staple crop. Cowpeas, groundnuts, maize, pumpkin, okra and other vegetables are also grown. Although some households use machines or simple ploughs to cultivate the land, most of it is tilled by hand.

The livestock sector is a major contributor to the economy of South Sudan, valued at US $3 billion and contributing roughly 25 per cent of GDP. Livestock rearing is an important tradition in the pastoral communities serving a key role in their social, cultural, and economic systems. Common farm animals include cows, goats, and sheep. During the dry season, the pastoral communities from the surrounding Sudano-Sahel eco-regions migrate with their cows towards the Sudd in search of pasture and water (Ruuskanen, 2021).

There is a variety of natural resources including papyrus grasses (for making mats), water lilies, gum Africa, doum, wood for fuel wood and construction, fish, crustaceans, and birds. Reserves of crude oil are present in the zone. Fishing is an important livelihood

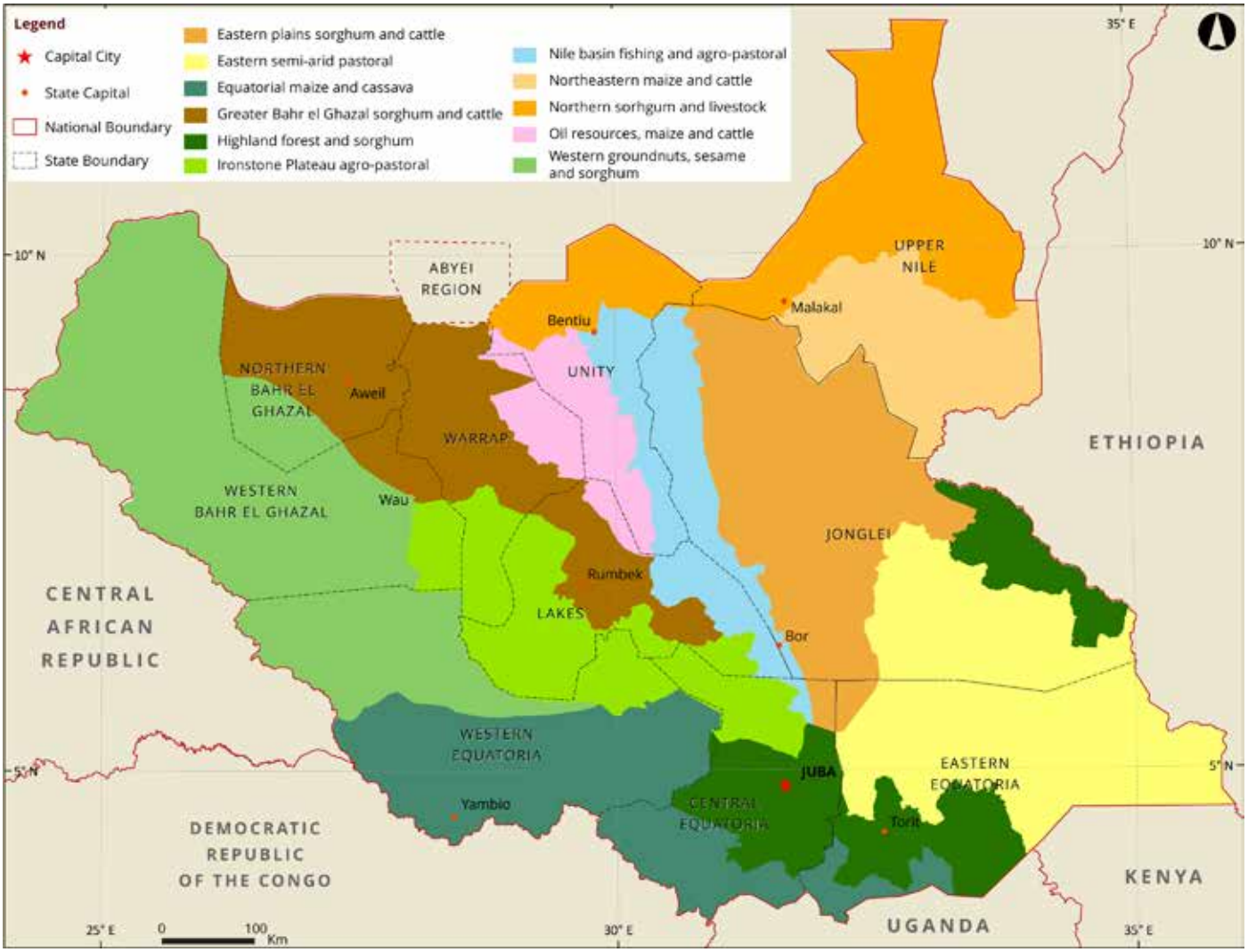


Figure 7: *South Sudan livelihood zones, 2018 (FEWS NET, 2018). Most of the Sudd falls within Nile basin fishing and agro-pastoral zone (area in blue).*

option, especially for poorer households. It is primarily artisanal employing the use of canoes, spears, and nets. Other products that contribute to household food security include Lalop (Desert dates), roots, tubers, vines, leafy greens, honey, and game such as antelope and dik-dik. Many of these can be processed for sale or later consumption. These are highlighted in Table 2.

The market system is not very active as the swampiness and remoteness of the area combined with unreliable transport combine to make road access to areas beyond the river complicated. Canoes and motorboats are the most used means of transport.

Table 2: *Characteristics of the Nile Basin Fishing and Agro-pastoral Livelihood Zone (SS08). (MP= Market-purchased food; OP = Own produced crops, IK = In Kind (payment), G = Gathering, usually for wild foods or products) (FEWS NET, 2018)*

Main productive assets	
Poor	**Better-off**
0.5 ha cultivated fishing equipment cattle, goats, sheep	>1 ha cultivated Fishing equipment cattle, goats, sheep
Main foods and sources	
Poor	**Better-off**
Sorghum (OP/MP) Maize (OP) Groundnuts (OP) Cowpeas (OP) Fish (G) Water lilies (G) Other wild foods (G) Vegetables (OP) Milk, meat (Kin, IK, OP)	Sorghum (OP/MP) Maize (OP) Groundnuts (OP) Cowpeas (OP) Milk, meat (OP) Fish (G/MP) Water lilies (MP) Other wild foods (MP) Vegetables (OP)
Main income sources	
Poor	**Better-off**
Sale of fish, river products, wild foods, and bush products Sale of vegetables Labor sales Sale of beer Sale of goats	Sale of milk and milk products Sale of fish Sale of sorghum, maize, vegetables Sale of cattle, goats, sheep Retail trade
Main markets	
Malakal (outside the zone) – main fish market Gut Thom – livestock, cereal, fresh and dry fish Panyijiar, Awerial, Ayod – livestock River ports (critical for trade)	
Main hazards	
Flooding every 3-5 years (and annual rise of river levels) Crop pests (arthropods, arachnids, crustaceans, and fungi treated by application of ash) Livestock diseases (CBP, PPR, Trypanosomiases, East Coast Fever, CCP, Foot and Mouth disease and internal worms and parasites) Cattle raiding (localized)	
Coping strategies	
Poor	**Better-off**
Increase fishing Increase labor sales & migration Increase wild food consumption Sale of small livestock Kinship support	Increase sale of livestock Increase formal employment Reduce number of employees or casual laborers

Ecosystem goods and services

An ecosystem is defined as a functional unit made up of non-living and living components such as micro-organisms, plants, and animal including humans. There is a wide variety of habitats including aquatic, forests, grasslands, and agricultural ecosystems. Ecosystem services are the benefits provided to humans through the transformation of the environmental assets into goods and services. Some of the environmental assets may include the atmosphere, land, water, nutrients, and vegetation while the goods and services include provision of water and clean air (Figure 8) (MEA, 2005).

If managed well, the Sudd is potentially a rich economic asset to South Sudan as it could provide income, jobs, and irreplaceable ecosystem services into the foreseeable future. The economic value of the Sudd, which represents only a fraction of the total value of the Sudd's non-economic values, includes its potential as a symbol of national identity, its role in climate change mitigation, regulation of the flow of the White Nile, and supporting South Sudan's unique wildlife and culture (Gowdy & Lang, 2016).

The total economic value (TEV) of the Sudd wetland in 2015 was estimated at about US $3.3 billion (Figure 9). Annual provisioning services for the community are estimated at more than US $253 million while it also contributes about US $53 million worth of water supply services. The wetland also provides regulating and biodiversity services worth about US $1.8 billion and 1.2 billion, respectively in the form of microclimate regulation, flood control, and water regulation. Table 3 highlights these estimates in more detail (NBI, 2020).

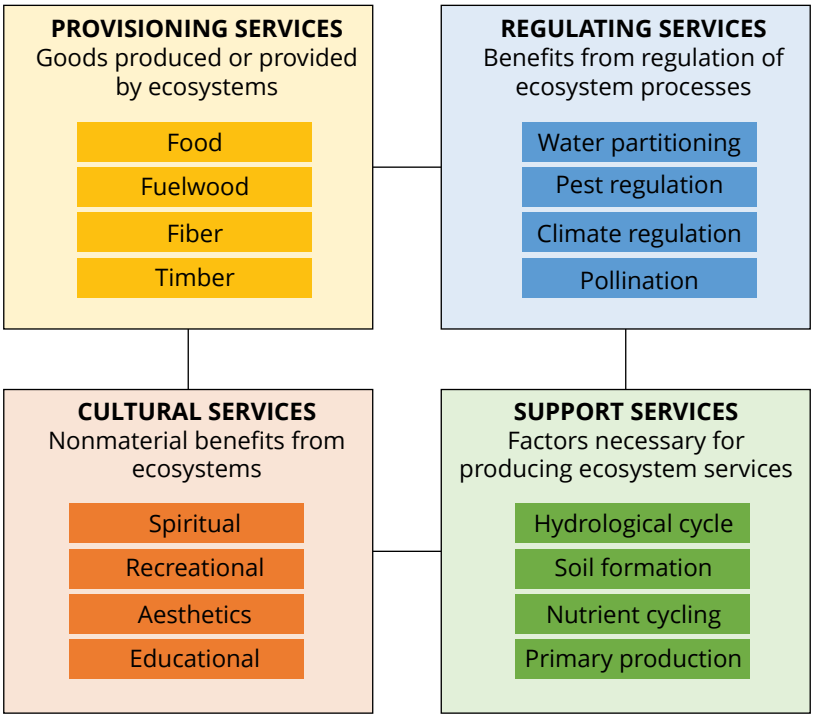


Figure 8: *Classification of ecosystem services (MEA, 2005)*

Cows on the road to Bor, Jonglei state
Photo credit*: BBC World Service/flickr*

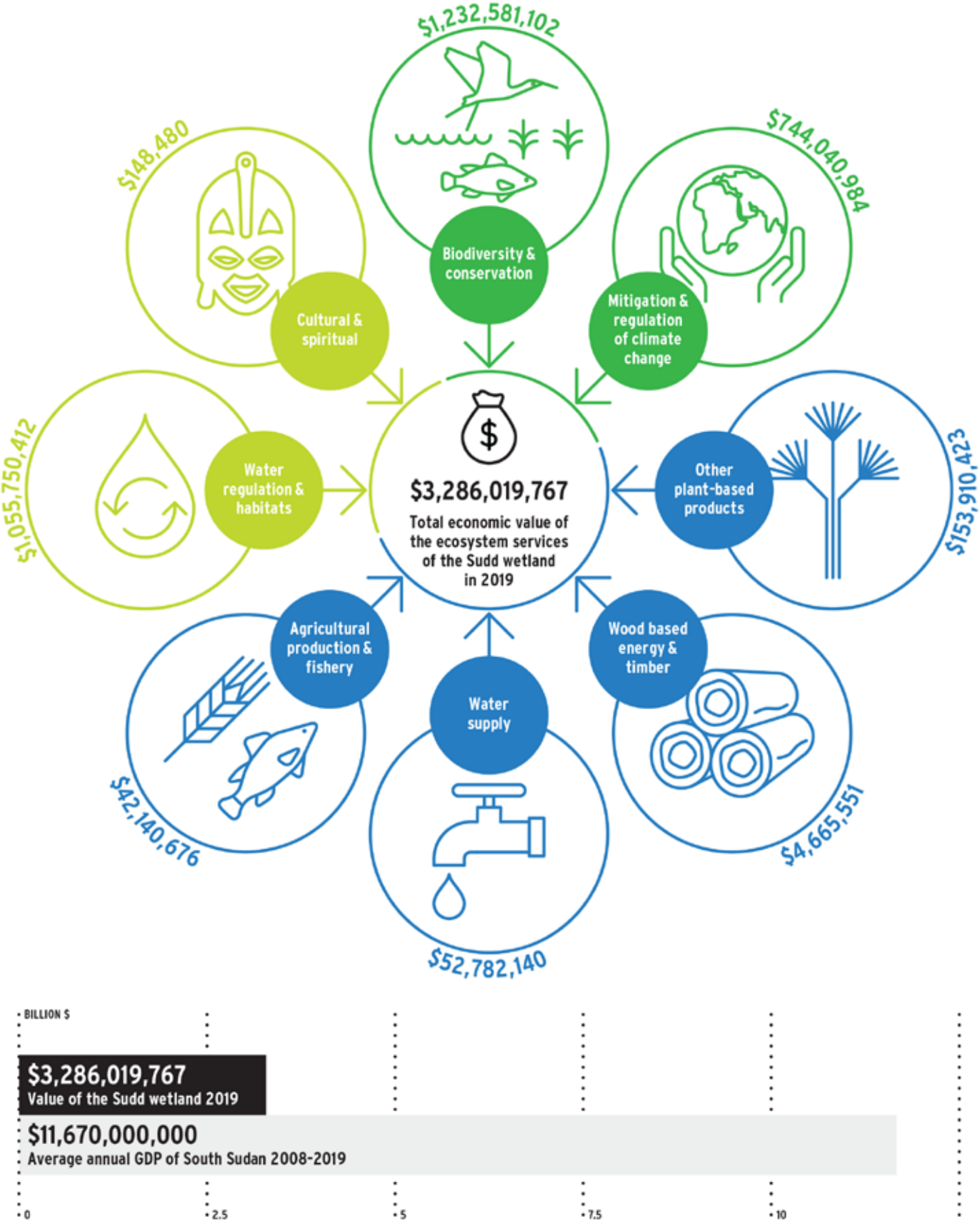


Figure 9: *The real value of the Nile Basin Wetlands (Rutagwera, 2021)*

Table 3: *Total economic valuation of different ecosystem services of the Sudd wetland (NBI, 2020)*

Ecosystem services		Indicator	Size (ha) or population	Unit value $ (ha) or per capita value	Total Value
Provisioning	Crop	Value of crop produced per year	131,112	299	35,793,576
	Fish	Value of fish harvested per year	89,352	77.8	6,347,100
	Papyrus	Value of papyrus harvested from the wetland	480,965	19.5	8,563,269
	Papyrus crafts	Value of mats and crafts made of papyrus	480,965	47.95	21,056,857
	Domestic water supply	Value of water supplied to households	160,000	35.3	5,156,870
	Livestock watering	Value of water consumed by livestock	1,786,336	2	47,625,271
	Livestock grazing	Value of livestock grazing	1,786,336	0.2	119,063,178
	Fuelwood	Value of fuelwood collected from the wetland	264,168	4.58	1,104,681
	Natural medicine	Value of natural medicine from the wetland	2,985,750	0.91	2,480,769
	Charcoal	Value of charcoal from the wetland	5,000	0.3	3,560,870
	Vegetation	Value of vegetation (reeds, bamboo)	1,141,263	0.56	583,532
	Mulch	Value of grass for mulching from the wetland	16,920	140	2,162,817
Total provisioning service					**253,498,790**
Cultural	Transport	Value of transportation using the open water of the wetland	89,352	1.82	162,621
Total cultural services					**148,480**
Regulating	Microclimate regulation	Value of microclimate regulation service of the wetland	3,075,102	265	744,040,984
	Flood control	Value of flood controlling service of the wetland	3,075,102	723.89	971,519,357
	Water regulation	Value of water regulation service of the wetland	3,075,102	30	84,231,055
Total regulating services					1,799,791,396
Biodiversity	Biodiversity	Value of biodiversity (habitat/ refugia) service of the wetland	3,075,102	439	1,349,969,778
Total biodiversity service					1,232,581,102
Total (Provisioning + Cultural + Regulation + Biodiversity),					3,286,019,767

Wetlands as a source and sink of GHGs

Wetlands have an extraordinary capacity to sequester and store carbon from the atmosphere, but this role is generally under-estimated. Wetlands cover almost a tenth of the Earth's surface and hold over a third of global terrestrial carbon (COA, 2012). One reason why they accumulate carbon so successfully is that they are water-logged, dark, and very productive, which creates conditions for highly stable carbon content. Carbon is stored in vegetation above ground and underground, in sediment beneath live plants, and in dead plants, such as leaf litter.

Wetlands are also a prominent source of Greenhouse Gases (GHGs) and under certain circumstances the same wetlands could either be net sink or net source of GHGs. The reason behind this dual nature is not well understood (COA, 2012). Clearing or drainage of wetlands can lead to large losses of stored organic carbon to atmospheric carbon dioxide. Also, under anaerobic conditions, wetlands can produce greenhouse gases such as methane and nitrous oxide, though this is reduced in salt water.

The Sudd wetland as a source and sink of GHGs

Figure 10 highlights the high soil organic content in the Sudd wetland. It is thought that rewetting wetlands (as happens during the flooding periods) leads to carbon sequestration while drainage of wetlands releases carbon dioxide into the atmosphere. This is yet to be confirmed through research and if proven, presents a potentially big opportunity for climate change mitigation (Darbyshire, 2021).

The Sudd peatland

Peatlands in the Sudd wetland are estimated to cover an area of 15,780 km^2 or about 50 percent of the total peatland area and 37 per cent of the total carbon stock of the entire Nile basin, making it the most important concentration of peatlands in the Nile basin area (Figure 11 and Figure 12) (NBI, 2019).

Peatlands are areas of high carbon sequestration and storage and thus are crucial for climate change mitigation. In addition, they provide critical ecosystem goods and services, such as tourism, fishing, water

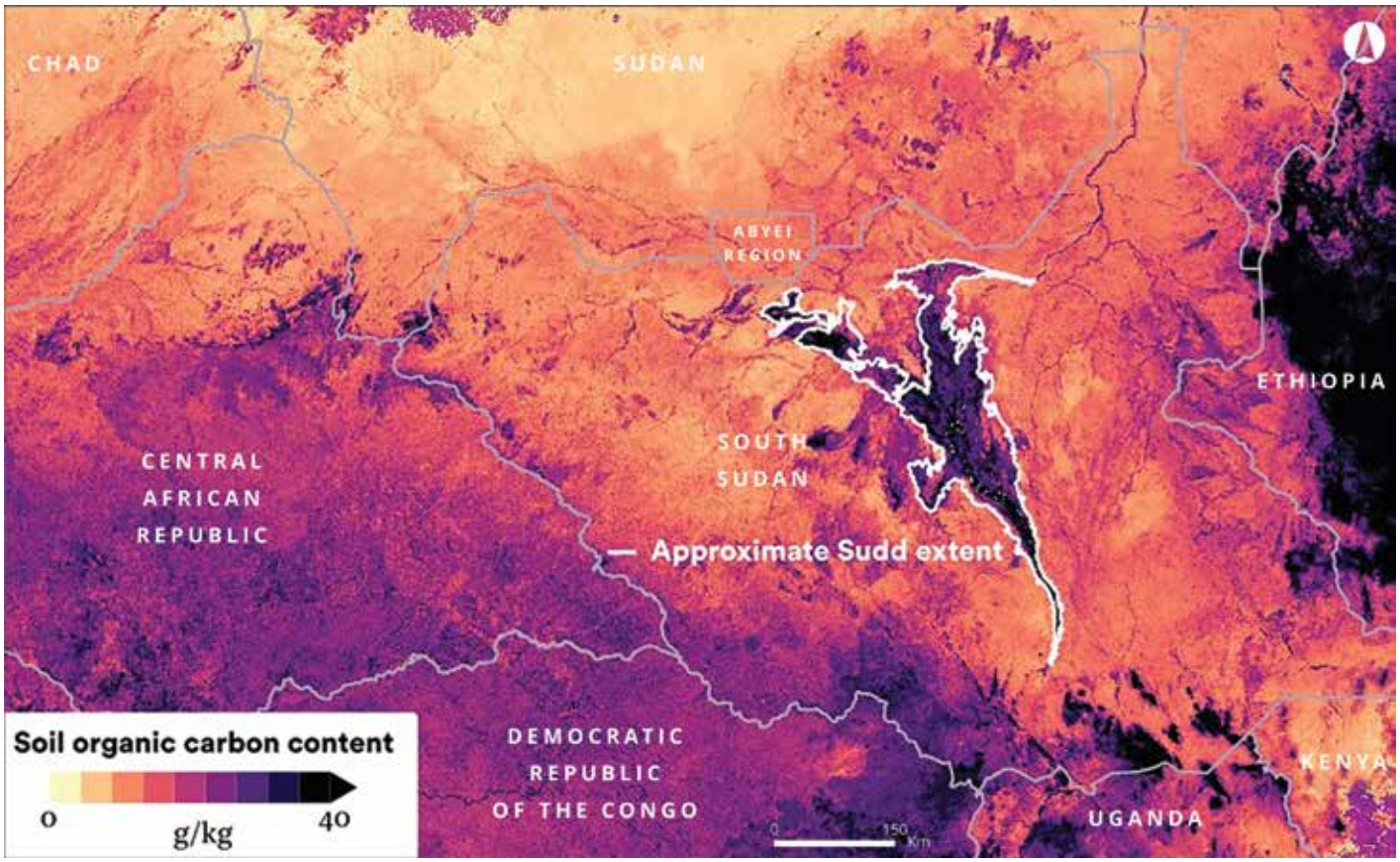


Figure 10: *The Sudd is both a carbon source and sink – the balance is not yet understood, and this remains a major knowledge gap. Soil carbon data from International Soil Reference and Information Centre (ISRIC) Africa Soil Grids. (Copernicus Sentinel data 2021) (Darbyshire, 2021).*

Peatlands

Peat is made from partially decayed plant material that collects under waterlogged conditions over time. Areas covered by peat are called peatlands. Other names for peatlands include mires, bogs, fens, peat swamp or swamp forests. Peat is found all over the world – in the permafrost regions, at high altitudes, in coastal areas, beneath tropical rainforest and in boreal forests. Peatlands store large amounts of carbon and though they cover less than three per cent of global land surface, estimates suggest that peatlands contain double the amount of carbon as the world's forests (GPI, 2016).

supply, habitat for biodiversity, flood control and drought buffering among others. These benefits make peatland restoration and conservation critical in the bigger picture of integrated water resources management and climate change in the Nile Basin (NBI, 2019). Since not much is known about the Sudd peatlands, there are prospects for soil organic carbon research for possible carbon offsetting and trading as an opportunity for climate change mitigation and adaptation (NBI, 2021).

There are also prospects for the GoSS to join regional and thematic partnerships like Global Peatlands Initiative (GPI, 2016) where nations work together to improve the conservation, restoration, and sustainable management of peatlands. Currently, the Global Peatlands Initiative is active in Indonesia, Peru, Democratic Republic of Congo, and the Republic of Congo.

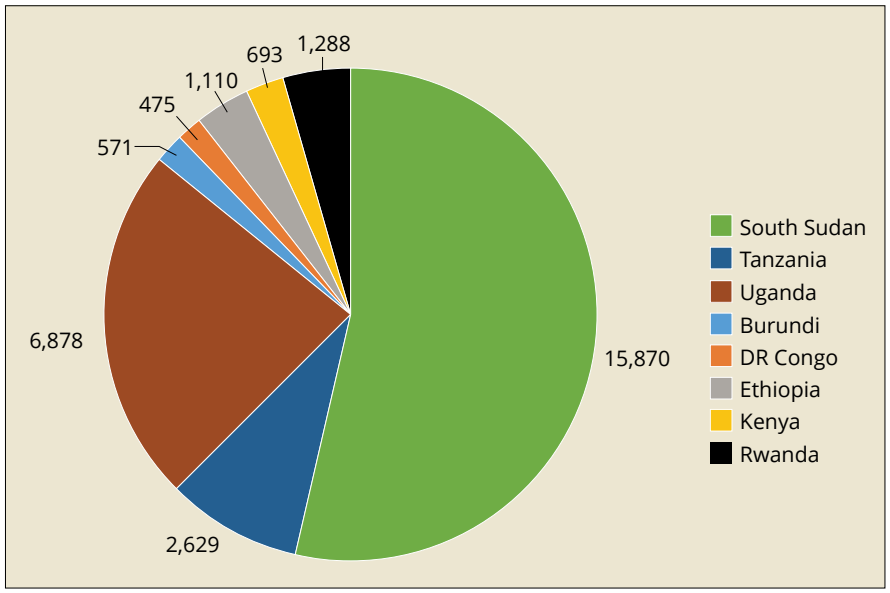


Figure 11: *Proportional distribution of peatlands in the Nile Basin in km² (NBI, 2021)*

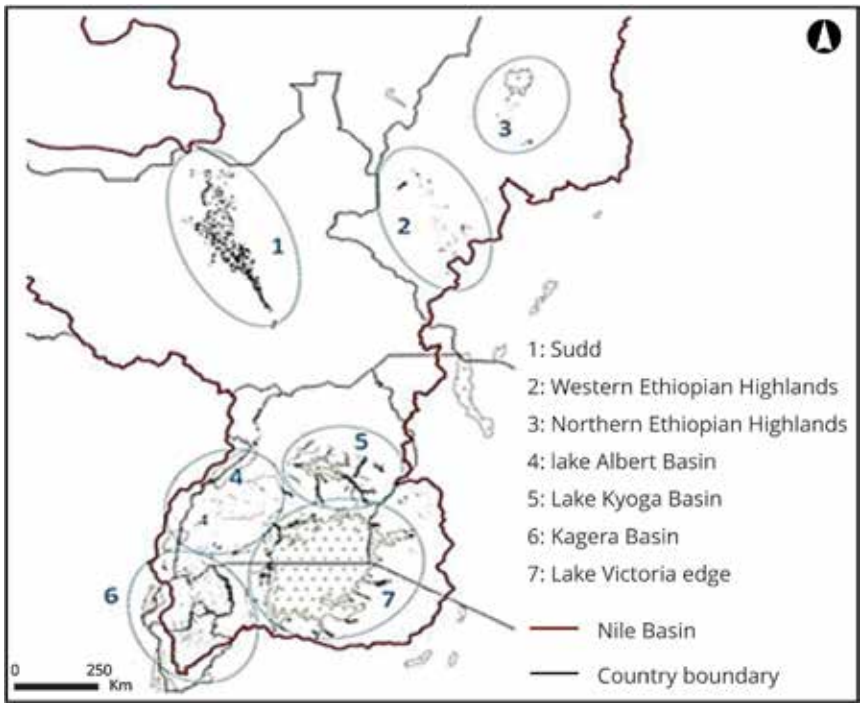


Figure 12*: Peatland areas in the Nile Basin (NBI, 2020)*

Methane emissions

The question of how methane (CH_4) emissions from tropical ecosystems such as wetlands and their response to climate change is one of the biggest ambiguities related with the global CH_4 budget. This has primarily been due to a historical lack of *in situ* data a situation which is particularly challenging in Africa.

A recent study attributed a large part of the increase in African emissions between 2010 and 2016 to the increasing wetland extent of the Sudd, driven largely by increased water levels in the upstream East African lakes. Emissions from the Sudd wetland were found to have increased during the study period by 3 Tg yr-1 (Lunt, et al., 2019). Another research paper assessed methane emissions from the wetlands of South Sudan using 2 years (December 2017–November 2019) data from the TROPOspheric Monitoring Instrument (TROPOMI) a satellite-based system that provides observations of atmospheric methane (CH4). An annual wetland emission of 7.4 ± 3.2 Tg yr-1, was estimated which agrees with the Lunt et al. (2019) study (Pandey, et al., 2021).

Atmospheric ammonia

Ammonia is an air pollutant which, in increased concentrations, can lead to heart and lung-related illness, make soil more acidic, promote eutrophication and hinder plant growth. It is emitted naturally from soils and vegetation fires. Agricultural activities such as livestock rearing, and fertilizer use are major contributors. Expanding agriculture and increasing populations are combining to push ammonia emissions up.

In swampy areas, the concentrations of ammonia are linked to the variations in the extent of flooded wetland. As the wetland soils dry out, ammonia emissions into the environment increase and vice versa. In wetter years, ammonia concentrations were lower (Figure 13) (Hickman, et al., 2021). A study of changing atmospheric ammonia concentrations in Africa from 2008 to 2018 showed that the Sudd was the only region in Africa that showed a clear decrease in ammonia over the study period. The message for policy is the need to maintain wetland ecosystem health as it contributes to decreases in emissions of atmospheric ammonia (Hickman, et al., 2021).

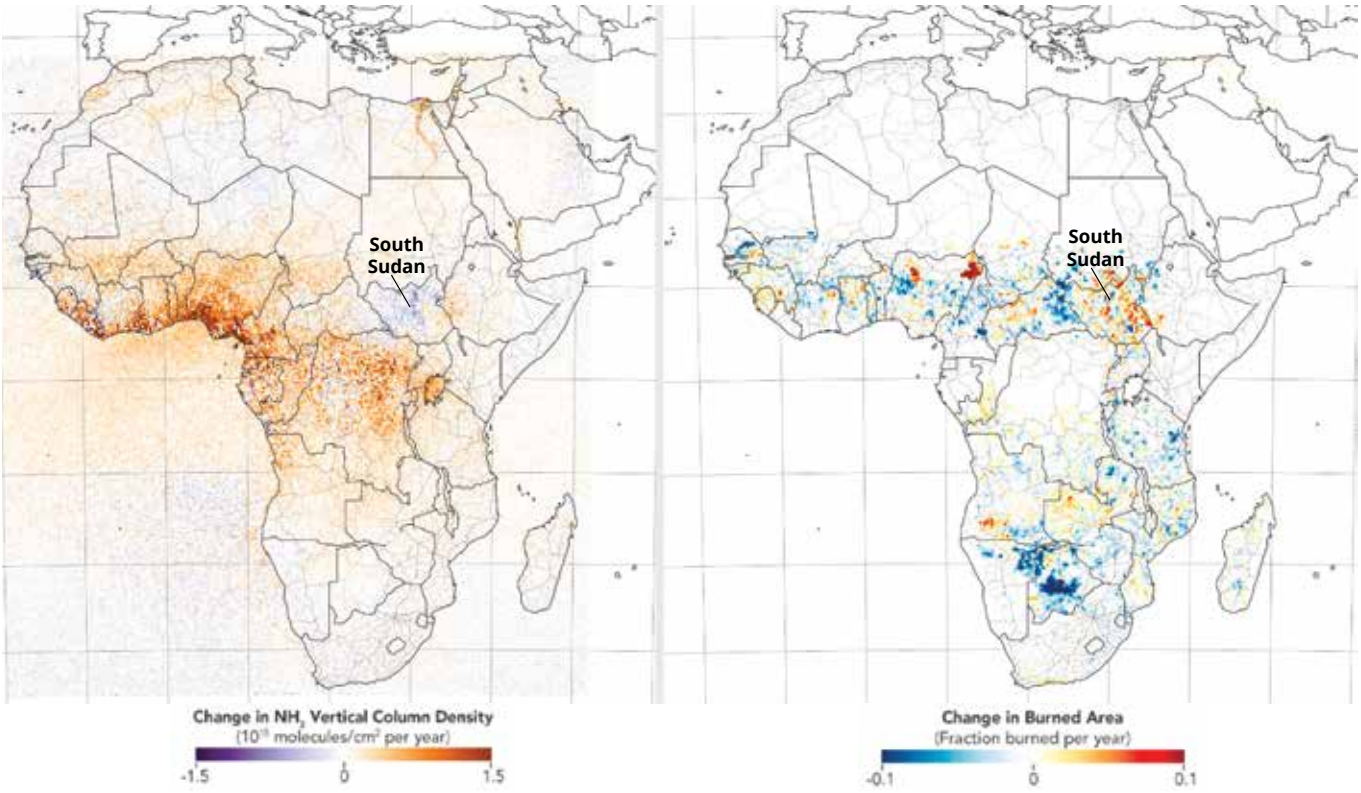


Figure 13: *Changes in ammonia concentration in three regions of Africa from 2008 to 2018.*
The map on the left depicts the change in ammonia concentration in three regions of Africa from 2008 to 2018. The map on the right shows changes in burned area between 2008 and 2018. While biomass burning is one source of ammonia concentration increase, agricultural activities such as raising livestock and using fertilizer are also major sources. In West Africa and Lake Victoria, concentration increased over time. In South Sudan, it decreased (Credits: NASA's Earth Observatory / Joshua Stevens)

Oil

Oil reserves in South Sudan are estimated at over 3.5 billion barrels of crude oil. This is Sub-Saharan Africa's third largest reserves after Nigeria and Angola, respectively. The energy industry of South Sudan is of interest as it has the potential to become a vehicle for economic and social development (MoP, 2020). However, oil exploration and production which has been going on for some time is also a threat to the Sudd.

The oil-producing block 5A (Figure 14) spans a section of the Sudd and production in the southern portion restarted in June 2021 after oil production had halted for almost eight years after the civil war. The Bentiu oil refinery resumed production in August 2021 after incurring damage during the conflict in 2014. Further, the improved relations between the Republic of Sudan and South Sudan is likely to ensure the continued flow of oil. Even as developments proceed in the oil sector, decision makers must pay attention to the degradation of the Sudd wetland through oil contamination as this has severe consequences for the health of both the people and the wetlands.

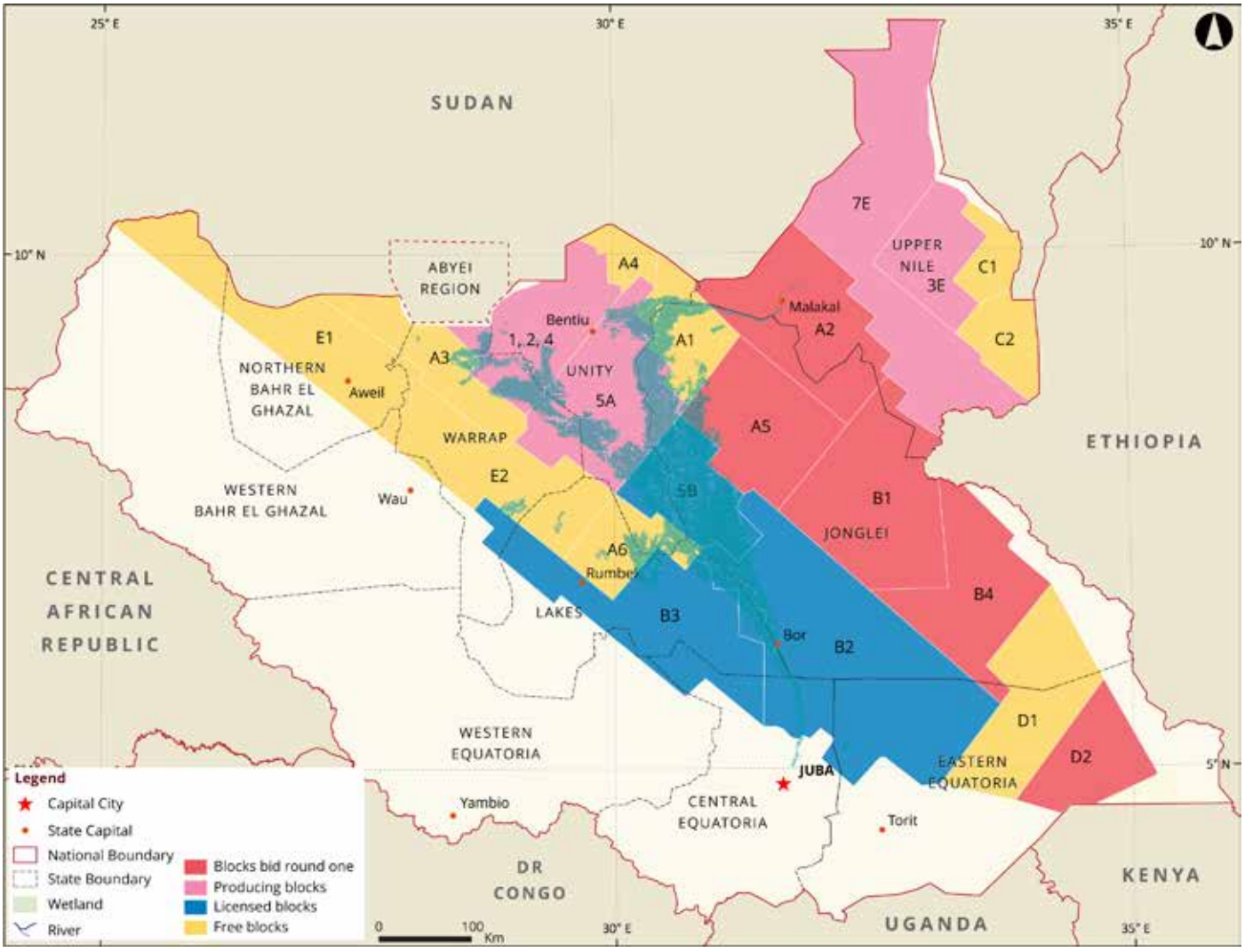


Figure 14: *Map and status of oil blocks in South Sudan (Darbyshire, 2021)*

3. Driving Forces

Human activities are some of the main driving forces behind environmental change and degradation in the Sudd Wetland. These include insecurity and relative peace, geopolitics and changes to the hydro-meteorological regime, climate change and human-induced land use change.

Insecurity and relative peace

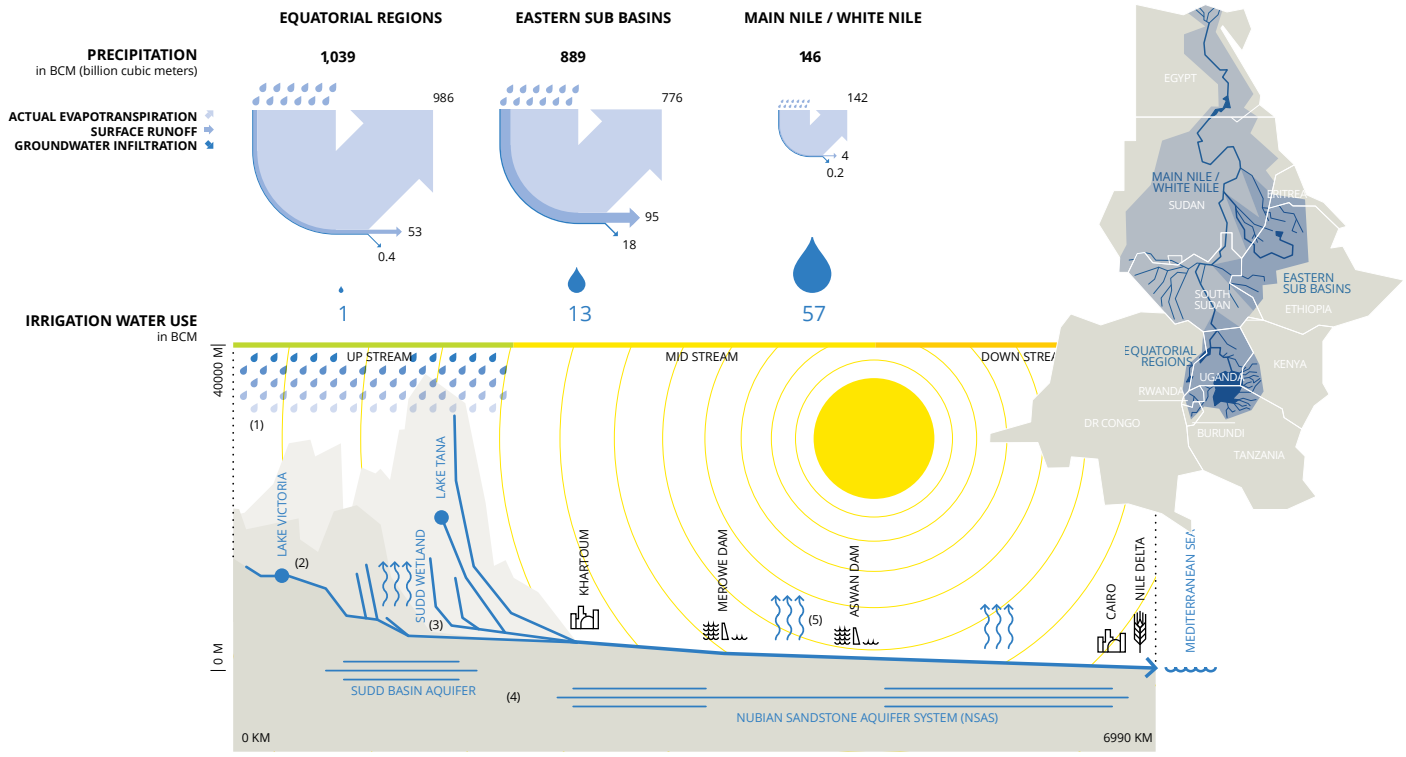
South Sudan has endured decades of conflict and instability which are known to affect the environment directly and indirectly, for instance through the disruption of productivity and responsible natural resources management practices. Apart from the attendant environmental degradation, conflict also destroys the institutions that are critical for human and environmental wellbeing. After independence in 2011, the GoSS attempted to rebuild the institutions. Although there has been some progress, the challenges still exist. The capacity of the GoSS to formulate policy and implement programmes is still limited but is developing and evolving and should be further strengthened (UNEP, 2018).

Geopolitics and the shared hydrology of the Nile Basin

About 20 per cent of the Nile Basin lies within South Sudan, 7 per cent of which is covered by the Sudd wetland, making it regionally significant and an important part of the Nile basin water network (Figure 15) (NBI, 2020). The wetland is replenished by rainfall in the upstream areas. The wetland acts as a sponge regulating and purifying the Nile waters, is a source of food and water for wildlife, people, and their livestock and, plays a role in climate change mitigation. The Nile waters are vital to the downstream areas of the Nile basin where water demand is on the increase.

About 50 per cent of the inflow to the Sudd swamps is lost to evaporation. To address this, plans were approved in 1974 to build the 360 km long Jonglei Canal to redirect the Nile water from Bahr el Jebel at Bor directly to the junction of the White Nile with the Sobat River. The premise was that the current evaporation rate of the wetland would significantly reduce, thereby releasing an additional 5% to the water volume for the downstream countries at Aswan. The upshot was that the Jonglei Canal construction

Settlements along the White Nile in the Sudd wetland.
Photo credit: *Michael Lopidia, WCS*



UNDERSTANDING THE NILE: WHERE IS THE RIVER COMING FROM, WHERE DOES IT GO

(1) WATER TOWERS
Specific regions in the Nile Basin generate most of the Nile water flow. These high-altitude areas experience heavy rainfall and lower temperatures. The main water towers within the Nile Basin are the Ethiopian Highlands, Mt. Elgon, Mt. Rwenzori and the Albertine Rift.

(2) LAKES
The Nile Basin has numerous lakes which play an essential role in regulating the flow of Nile water. Major lakes like Lake Victoria, Lake Albert, Lake Tana and Lake Kyoga significantly influence the outflow due to storage and regulation.

(3) SUDD WETLAND
The Sudd is one of the most extensive wetlands in Africa. It plays a significant role in minimising seasonal flow variations of the White Nile – it reduces flows due to high evapotranspiration, limits floods during the wet season and supports flow during the dry season.

(4) GROUNDWATER
The Nubian Sandstone Aquifer System (NSAS) is the largest transboundary groundwater resource in the Nile Basin region. Aquifers across the basin are highly heterogeneous, ranging from shallow local ones (actively replenished by rainfall), to deep regional systems

(5) EVAPOTRANSPIRATION
Evapotranspiration is one of the major components of the water balance over the Nile Basin, accounting for about 87 per cent of the Basin's rainfall. It however varies from one sub-basin to another based on land use/cover and the prevailing climatic conditions.

Figure 15: *Hydrology of the Nile (Rutagwera, 2019)*

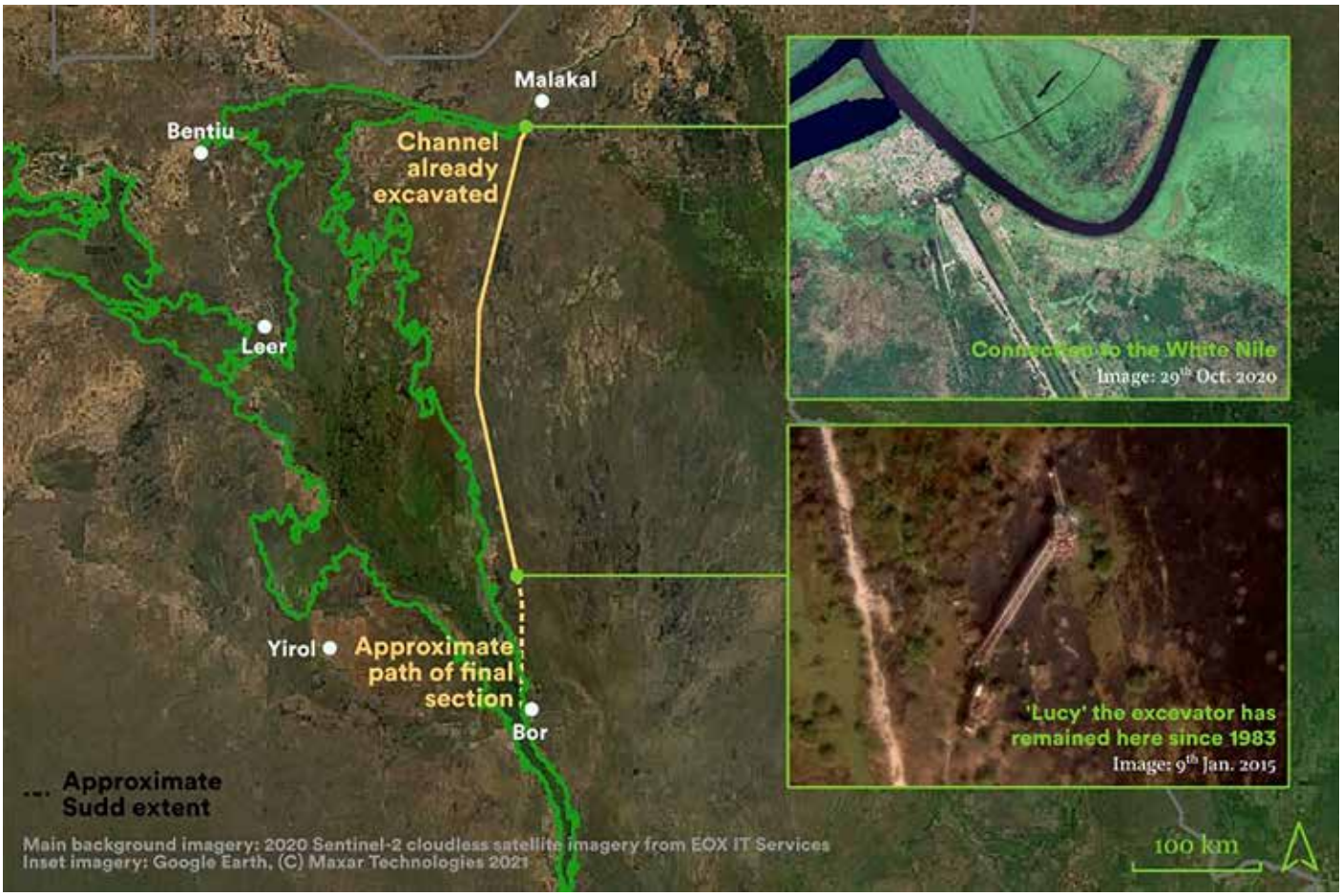


Figure 16: *Paths of the excavated and possible final section of the Jonglei canal (Darbyshire, 2021).*

would probably lead to a 30 per cent reduction of the Sudd wetland with negative impacts on the ecosystem and local livelihoods. For instance, it was thought it would reduce drinking water, fisheries, pasture, and access to either side of the canal by wildlife, pastoral communities, and their livestock (Mohamed, Hurk, Savenije, & Bastiaanssen, 2005). The civil war in 1983 led to the halting of construction work, by which time 240 km out of canal had been built as shown in Figure 16 (Mohamed , Hurk, Savenije, & Bastiaanssen, 2005).

Discussions around the re-opening of the Jonglei Canal remain sensitive for South Sudan. Despite the importance of the wetlands to the local and regional environment, its hydrology and interaction with the climate are still not well understood (Mohamed Y. A., 2006). It is important that any plan to develop the Sudd wetland should be based on a credible science and socio-economic information base. Although, since 2011, there have been sectoral plans that aim to address waterway expansion, oil production and national park planning, there is currently no integrated development plan for the Sudd (NBI, n.d.). It is recommended that ecosystem services be fully incorporated into any development plans and strategies for this area.

The hydro-meteorological regime

Rainfall and temperature

There are distinct wet and dry seasons in the Sudd region, with rainfall commonly occurring from April to October and cresting around August as shown in Figure 17. Annual rainfall varies across the country from 200 mm in the southeast, to between 700-1,300 mm in the northern states, to 1,200-2,200 mm in the forests of Western Equatoria and the Equatorian highlands (MoEF, 2021).

The data shows that since the mid 1970's there has been a 10–20 per cent decrease in the long rains. As a result, the area of regions receiving rainfall sufficient to support the livelihoods of agropastoralists (>500 mm) reduced by 18 per cent. Future rainfall projections for the years 2010–2039 show reductions of over 150 mm between June and September in some parts of the country (see Figure 18) (MoEF, 2021).

There has been a 0.4°C per decade increase in temperature over the last 30 years in South Sudan putting the country amongst the most rapidly warming nations globally (Figure 19) (MoEF, 2021). General circulation model projections indicate that temperatures may increase by 0.6-1.7°C by 2030 and by 1.1-3.1°C by 2060 relative to the baseline period of 1961–1990. It is predicted that there will be a simultaneous decrease in precipitation and combined with the increases in temperature will amplify the impact of droughts. A warming of more than 1°C would result in about 10-20 per cent reduction in precipitation through increased evaporation, which would further reduce the availability of water (MoEF, 2021).

The South Sudan Meteorological Service has an immensely important job to do providing weather and climate information in support of science, the economy and livelihood (farming and pastoralism) activities. Inadequate funding, outdated equipment and untrained staff are some of its current challenges. There is need for greater investment in weather stations and hydro-meteorological measuring equipment to accurately capture status and trends of changes in climate.

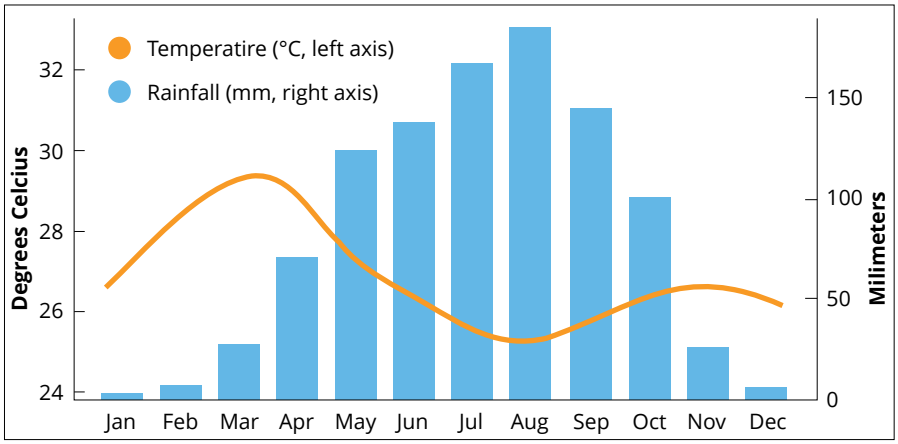


Figure 17: *Average monthly temperature and rainfall in South Sudan, 1901-2016 (MoEF, 2021)*

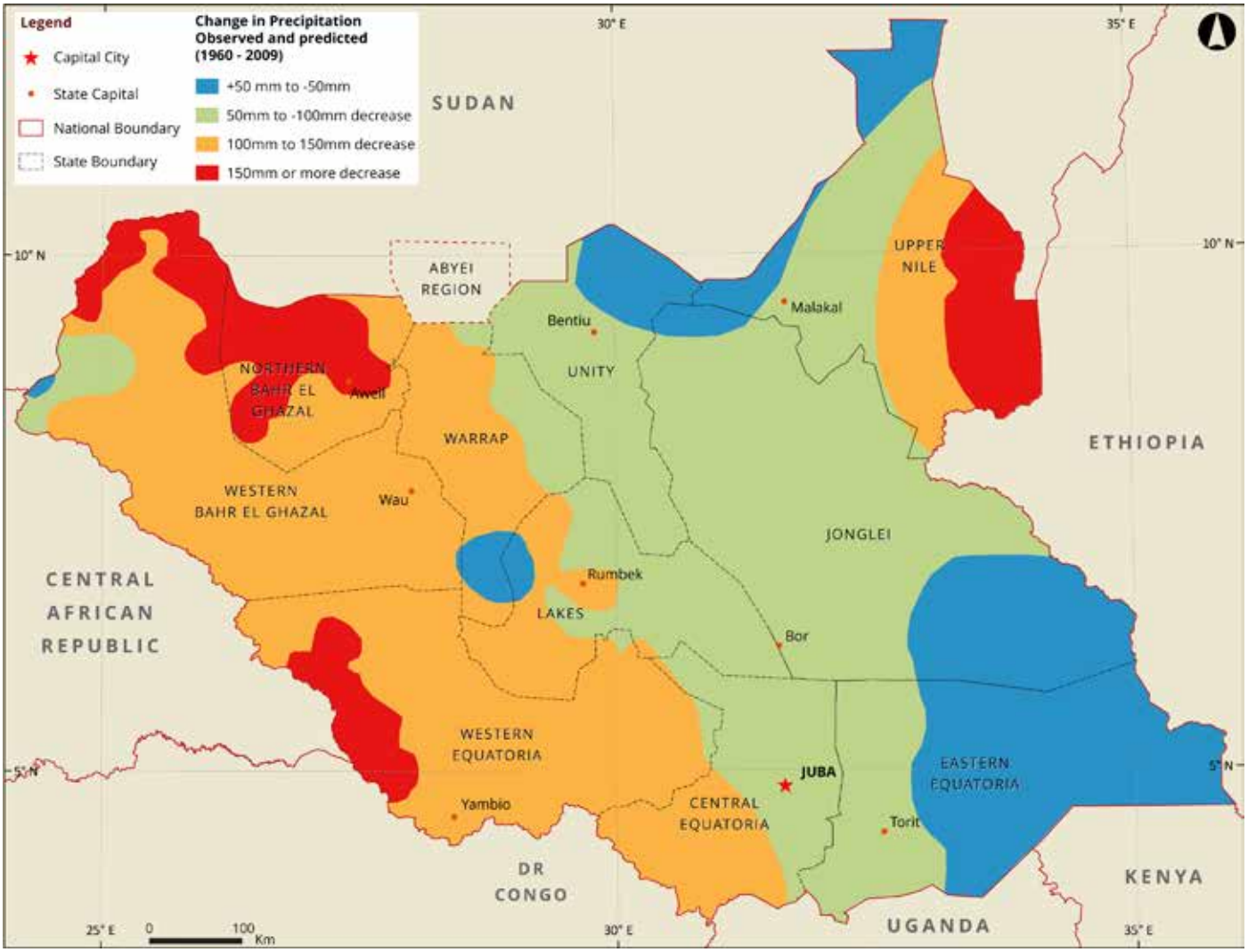


Figure 18: *Projected change in precipitation 1960-2039 (MoEF, 2021)*

Evapotranspiration

About 50 per cent of the waters of the White Nile evaporates as it passes through the Sudd amounting to approximately 16,000,106 m^3 per annum (Mohamed & Savenije, 2014). The boundaries of the Sudd are variable and depend on the regional climate (mainly outflow from Lakes Victoria, Kyoga, and Albert) and the local climate (characterized by precipitation and evapotranspiration over the wetland itself). Evapotranspiration is the combination of water loss through evaporation from open water, soil, and plant transpiration.

It is hypothesized that increasing rainfall and increased temperatures should lead to increased evapotranspiration. Data over the last century (1900-2000) show that water flow into and out of the Sudd increased probably linked to increasing precipitation over Lake Victoria and its catchment area in 1960 and 1961, although precipitation over the Sudd itself remained constant. Daily maximum temperatures increased by 0.6°C, while daily minimum temperatures increased by 1.5°C. Despite these increases, actual evapotranspiration over the wetland itself has not changed. It is thought that relative humidity and solar radiation (which both reduced by 10 per cent between 1950-2000) combined to compensate for the increased inflows and temperatures (Mohamed & Savenije, 2014). Figure 20 highlights some of the historical data on the Nile flows due to rain, evaporation, inflows, and outflows.

Understanding and measuring evapotranspiration is a critical component in water resources management. However, there are variations in the values for evapotranspiration depending on the models used as highlighted in Figure 21. This problem is compounded by data gaps and the need for capacity building in data analysis.

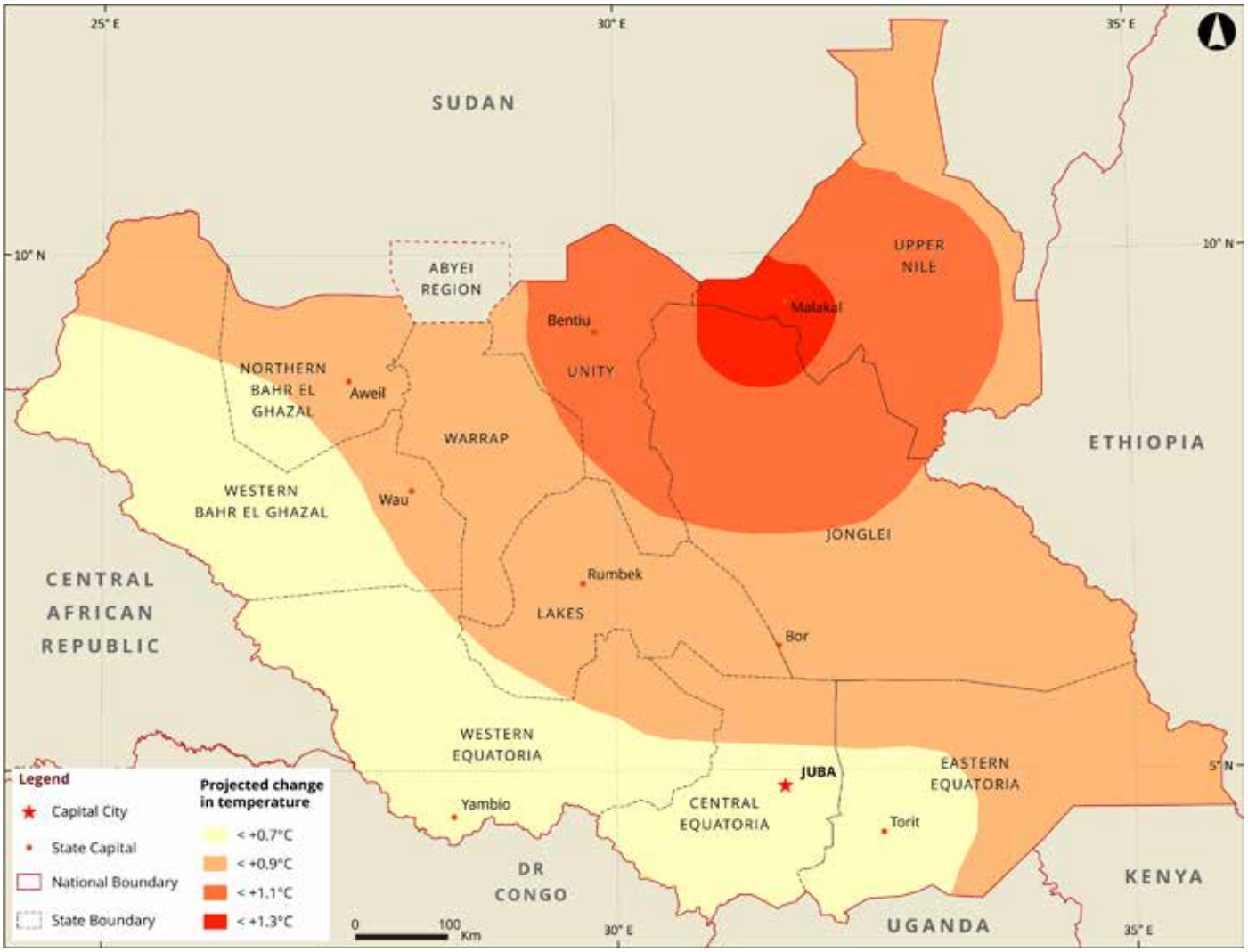


Figure 19: *Projected change in temperature 1960-2039 (USAID, 2016)*

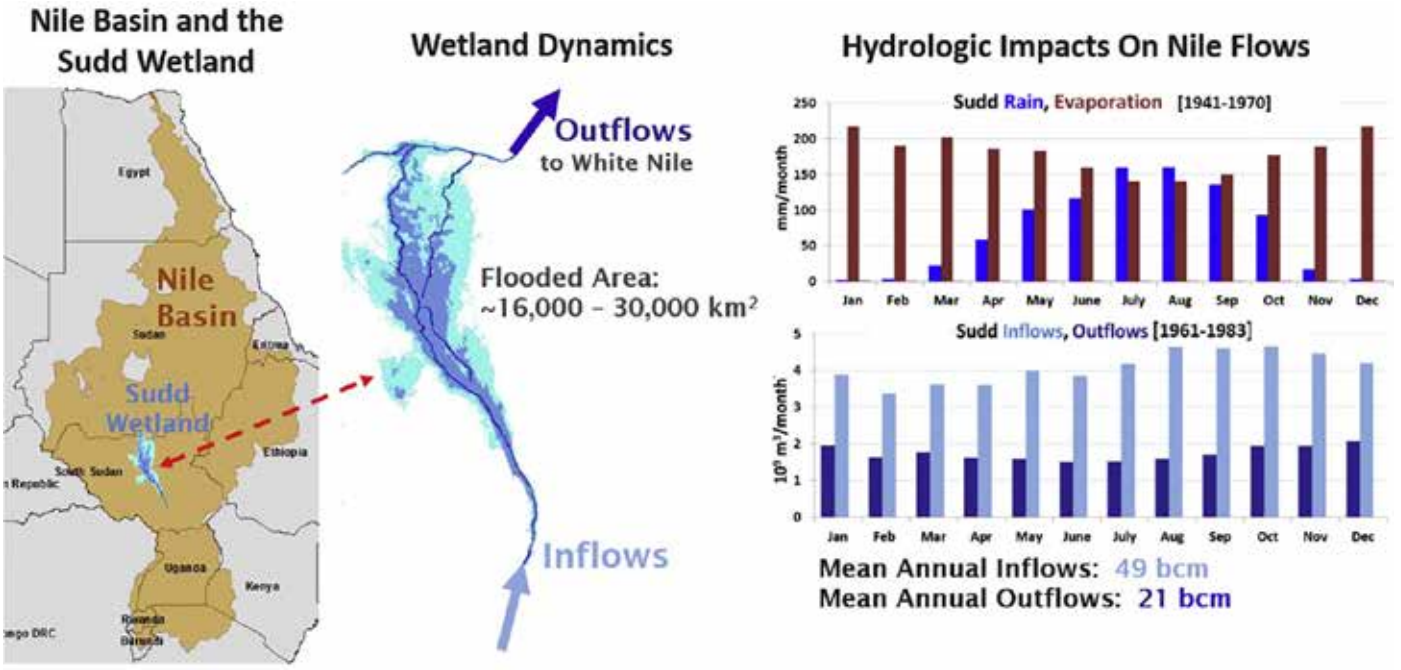


Figure 20: *Historical observations within the Sudd measuring rainfall, evaporation, inflows, and outflows (Di Vittorio & Georgakakos, 2018)*

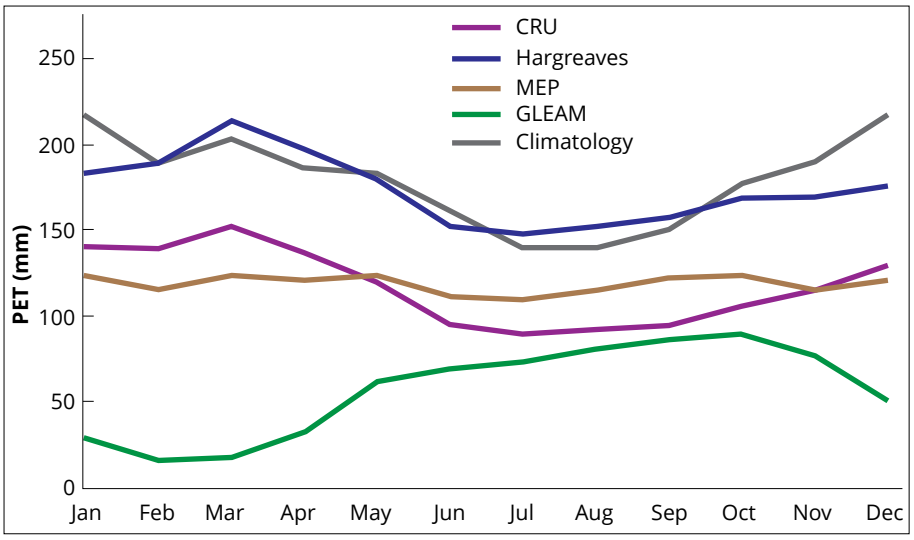


Figure 21: *Monthly mean gridded potential evapotranspiration estimates averaged over the Sudd flooded area extents, from 2000 to 2018, compared to the historical climatology estimates. This figure highlights the substantial differences between ET estimates from different models (Di Vittorio & Georgakaos, 2021)*

Implications for policy

There is need for accurate and credible scientific information to guide strategies for socio-economic development, ecosystem protection and water conservation projects in the region. Currently, data underlying the hydrodynamics of the Sudd is weak and raises more questions than it answers. Recent satellite-derived hydrologic data suggests that the existing Sudd model over-predicts the extent of the flood area and does not accurately capture the storage-attenuation characteristics of the wetland. Further, the remotely sensed information has been found to be somewhat inconsistent in terms of the Sudd water balance. (Di Vittorio & Georgakaos, 2021). Other data (Figure 22 and Figure 23) based on recent satellite measurements clearly show increasing lake height in Lake Victoria and Sudd (USDA, 2022).

Collecting groundwater hydrologic data in the Sudd using traditional methodologies is equally complicated due to the wetland's high spatial and temporal variability and insecurity on the ground, among others. However, satellite data indicates that the Sudd Wetland is a water-limited system. It has very shallow ground water storage and depends on surface water inputs (McGuinnes & Becker, 2019).

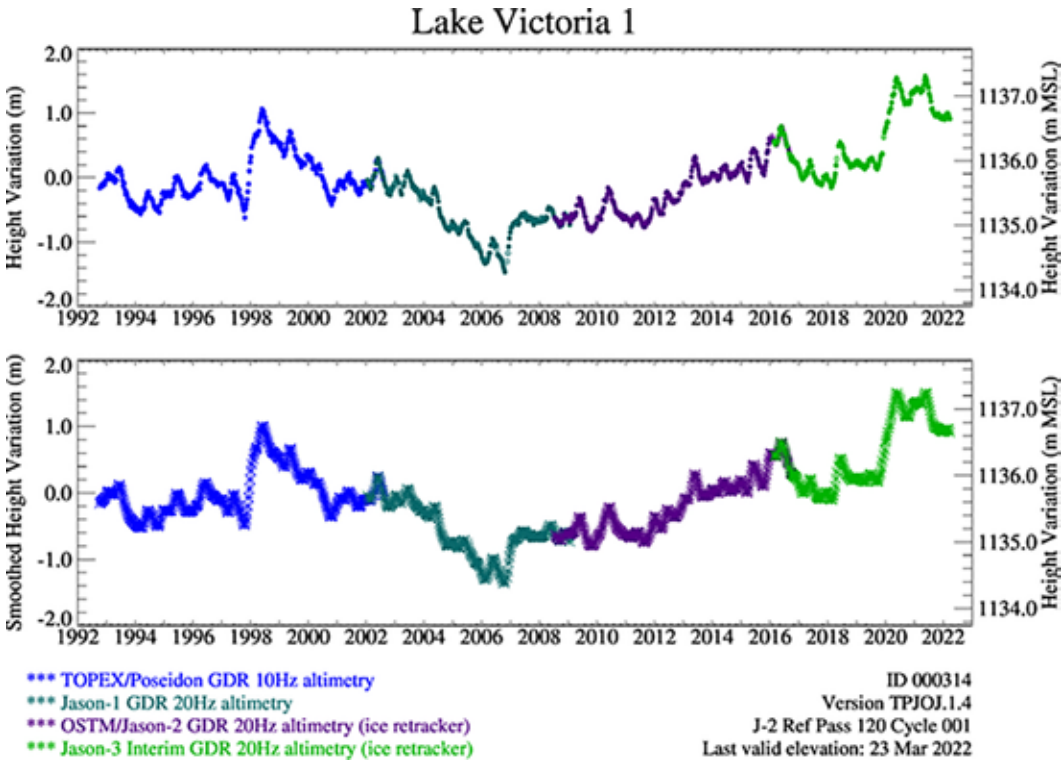


Figure 22: *Lake Victoria height increasing as measured by satellite data (USDA, 2022)*

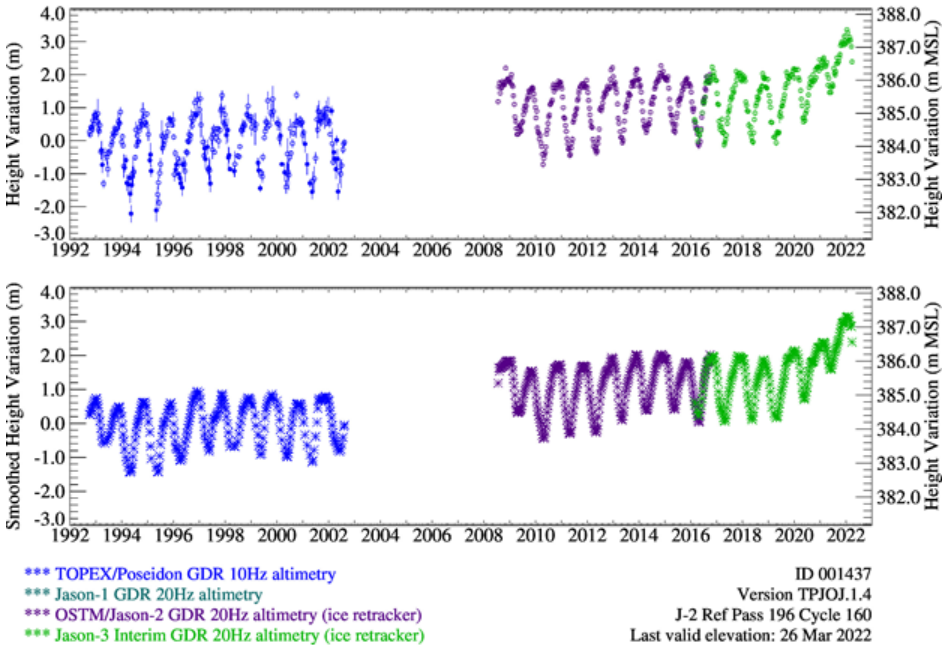


Figure 23: *Lake Jebel Aulia height increasing as measured by satellite data (USDA, 2022).*

Climate change and the Sudd ecosystem

Climate change is identified as a major threat to wetlands. Changes to the hydrology and rising temperature can change the biogeochemistry and function of a wetland to such an extent that important ecological services harm the environment instead. For instance, when wetland vegetation starts to decompose, water purification services may be compromised and instead nutrients released into the water. When the rate of decomposition is higher than primary production (photosynthesis) it may lead to a shift in the wetland function - from being a carbon sink to a carbon source (Salimi, Almuktar, & Scholz, 2021).

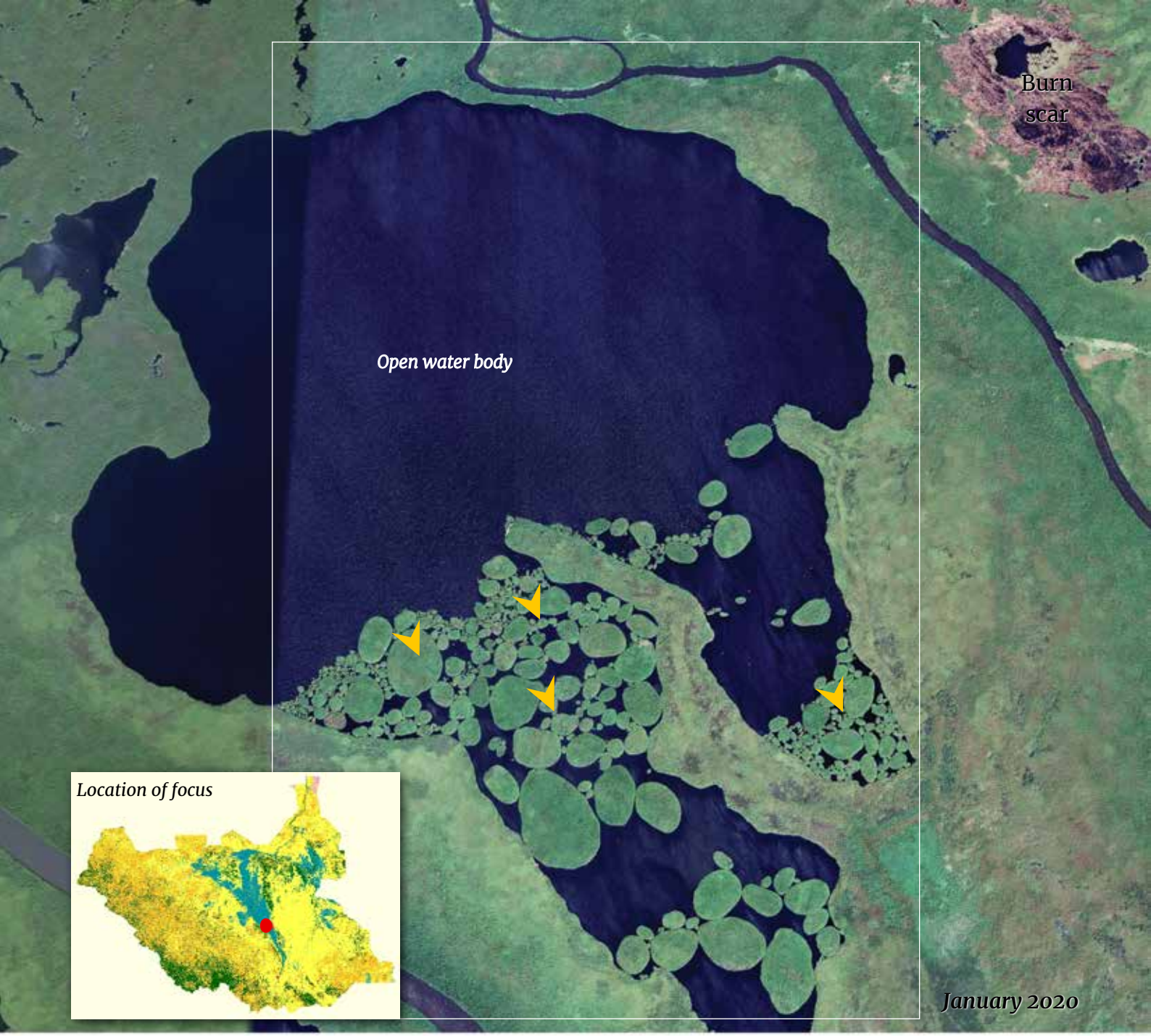
According to the latest IPCC report (IPCC, 2022) and quoted verbatim below, the following key trends are projected for the East African region:

- "During the short rainy season, a longer rainfall season and increased rainfall of up to over 100 mm on average is projected over the eastern horn of Africa and regions of high/complex topography at Global Warming Level (GWL) 4.5°C.
- During the long rainy season, there is low confidence in projected mean rainfall change. Although some studies report projected increased end of century rainfall, the mechanisms responsible for this are not well-understood and a recent regional model study has detected no significant change.
- Projected wetting is opposite to the observed 57 drying trends, giving rise to the 'East African rainfall paradox'.
- In other parts of East Africa, no significant trend is evident, agreement on the sign of change is low, and in some regions, CMIP5 and CORDEX data show opposite signs of change.
- Heavy rainfall events are projected to increase over the region at global warming of 2°C and higher. Drought frequency, duration and intensity are projected to increase in Sudan, South Sudan, Somalia, and Tanzania but decrease or not change over Kenya, Uganda and Ethiopian highlands".

Agriculture, health and food security are some of the sectors sensitive to climate change impacts. These and some of the resulting vulnerabilities are discussed in the sections that follow.

Agriculture

It is expected that impacts of climate change on the Lake Victoria and River Nile flow rates will ultimately impact the extent and seasonal fluctuation of the Sudd wetland and severely affect the pastoralist communities who depend mainly on agriculture and livestock as their source of livelihoods. Reduced rainfall will result in reduction in the availability of pasture and water for livestock and irrigation. Too much rain may result in floods, submerged fields (Figure 24), loss of harvests, livestock deaths which limits food stocks and collapses traditional livelihoods. Already, 2021 was the third year of flooding in this region and has led to the displacement of over 800,000 people (WFP, 2021).



Wetland dynamics in the Sudd as observed by satellite images of January 2022 and April 2022

The Sudd wetland undergoes seasonal changes that impact its hydrological, geomorphological and ecological processes. This is greatly influenced by seasonal flooding, and water flow from Uganda and eastern Central African Republic. These two images illustrate some of the seasonal changes that take place within the wetland. In the image from January 2020, most of the floating vegetation (labeled with yellow arrows) is within the southeastern portion of the open water body. In the next image, April 2020, the vegetation has changed location and is now mainly in the North East section of the open water. In the April image, however, some of the floating vegetation seems to have been cleared/harvested (brown patches labeled using red arrows). Although it cannot be stated with certainty without a proper field verification that the brown patches represent areas where vegetation has been cleared. It is common for fisher folk in the Sudd area to clear the vegetation in their "working areas" as they embark on their fishing activities.

Data Source: Satellite images from Maxar technologies acquired through Google Earth


Open water body

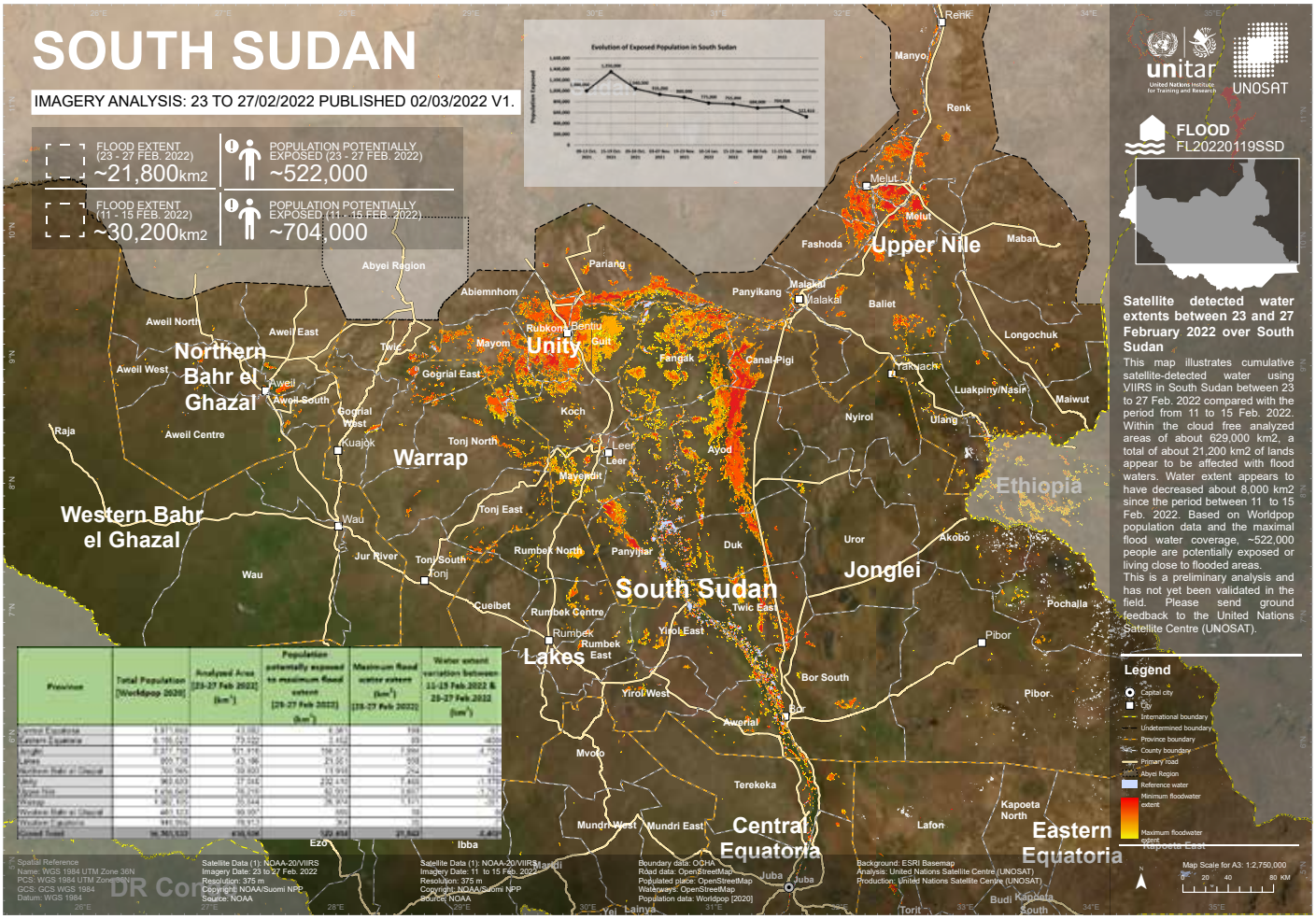


Figure 24: *South Sudan floods in 2021 (UNOSAT, 2022)*

Floods in a section of Bor town, Jonglei State.
Photo credit: *UNMISS/flickr*

Health and Food security

The changes in the rainfall regime are having direct and indirect impacts to human health, particularly as communities living in the Sudd already have limited access to clean drinking water, sanitation, and health services. The rising waters are habitat for mosquitoes and may lead to an increase in the incidents of malaria and other water-related and water-borne diseases (OCHA, 2022).

Habitat loss will reduce fish populations, affecting the fishing communities. Loss of arable land and increases in food prices may lead to malnutrition. Food insecurity results in reduced health outcomes in the form of acute malnutrition, famine, and death. Further, an expected increase in the number of extreme heat days can cause heat stress, while extreme precipitation can increase flooding and limit access to healthcare and other services (USAID, 2019).

Water and biodiversity resources

If the Jonglei Canal project goes ahead, together with climate change, it is likely to have negative impacts on human wellbeing, livelihoods, and the wetlands ecosystems. For instance, while the planned diversion of water through the Jonglei Canal would provide more water for downstream uses, it could affect the micro-climate of the area, and lead to reduced water availability for the current communities. Some other impacts include loss of biodiversity with impacts on the fish economy. It is likely to lead to resettlement of the pastoralist communities and impact their traditions and cultures that revolve around the wetland. The increase in frequency and duration of drought that is projected for South Sudan would only exacerbate the situation (Trisos, Adelekan, & Totin, 2022).

On the other hand, increases in precipitation would likely test the sponge-like ability of the Sudd to absorb the excess rainfall. While the Sudd is quite resilient to variations in rainfall, when combined with other drivers such as in-migration to the Sudd and associated changes in water demand, and the impacts of variable precipitation across sectors will be magnified especially in the drier years (USAID, 2019).

Loss of ecosystem services due to Land Use Land Cover Changes (LULCC)

A study of the LULCC of the Sudd wetland for different years (2015 to 2025 and to 2035) was undertaken for the wetland's total economic valuation. As seen in Figure 25 there have been increases in the wetland converted to crop land and grasslands while the amount of open water and vegetation cover declined.

Comparing the total economic value (TEV) across time for the different LULCC reveals that the TEV of the wetland declines from year 2015 to 2025 and then to 2035. However, this decline did not occur for all the ecosystem services computed in this study. The provisioning ecosystem services increased from 2015 to 2025 and then to 2035 mainly due to the increase in cropland and grasslands (Table 4). Decline in vegetation cover also led to a decline in cultural, biodiversity and regulating ecosystem services (NBI, 2020).

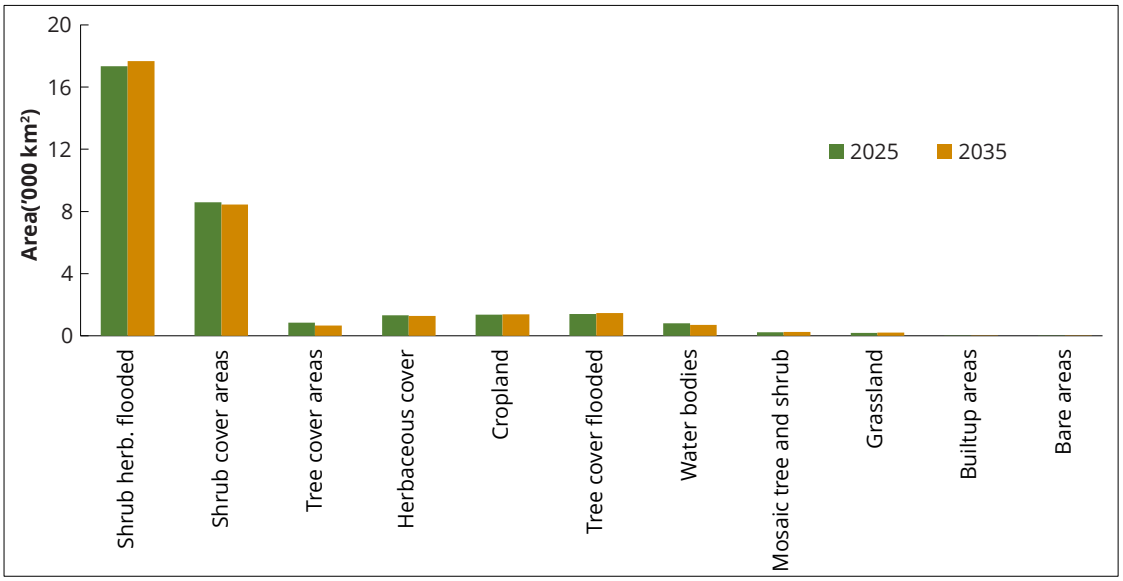


Figure 25: *Change in LULCC of the Nile Basin wetlands (2015 to 2025 and to 2035) (NBI, 2020)*

Table 4: *Change in total economic values of different ecosystem services with change in land use land cover 2015-2035 in US $ (NBI, 2020)*

Ecosystem service	2015	2025	2035	Change		
	Total Value	Total Value	Total Value	2015 to 2025	2015 to 2035	2025 to 2035
Crop	35,793,576	36,936,900	37,783,200	1,143,324	1,989,624	846,300
Fish	6,347,100	5,640,162	5,036,366	(706,938)	(1,310,734)	(603,796)
Papyrus	8,563,268	8,563,268	8,563,268	-	-	-
Papyrus crafts	21,056,857	21,056,857	21,056,857	-	-	-
Domestic water supply	5,156,870	5,156,870	5,156,870	-	-	-
Livestock watering	47,625,271	47,625,271	47,625,271	-	-	-
Livestock grazing	119,063,178	119,063,178	119,063,178	-	-	-
Fuelwood	1,104,682	1,029,544	989,818	(75,137)	(114,864)	(39,727)
Natural medicine	2,480,769	2,485,629	2,489,950	4,861	9,181	4,321
Charcoal	3,560,870	3,560,870	3,560,870	-	-	
Vegetation	583,533	565,349	552,771	(18,184)	(30,762)	(12,578)
Mulch	2,162,817	2,590,000	2,530,957	427,183	368,139	(59,043)
Total provisioning	253,498,789	254,273,897	254,409,374	775,108	910,585	135,477
Transport	148,480	131,942	117,817	(16,538)	(30,662)	(14,125)
Microclimate regulation	744,040,984	743,048,478	742,250,022	(992,506)	(1,790,962)	(798,457)
Flood control	971,519,357	970,223,409	969,180,838	(1,295,948)	(2,338,520)	(1,042,572)
Water regulation	84,231,055	84,118,696	84,028,304	(112,359)	(202,750)	(90,391)
Total regulating service	1,799,791,396	1,797,390,583	1,795,459,164	(2,400,813)	(4,332,232)	(1,931,419)
Biodiversity	1,232,581,102	1,230,936,913	1,229,614,187	(1,644,189)	(2,966,915)	(1,322,726)
GRAND TOTAL	**3,286,019,767**	**3,282,733,336**	**3,279,600,542**	**(3,286,431)**	**(6,419,224)**	**(3,132,793)**

4. Environmental Governance

Safeguarding the integrity of the Sudd wetland falls under the purview of several ministries. First is the Ministry of Environment and Forestry whose mandate is the development of a policy and regulatory framework for wetlands and biodiversity management; and secondly the Ministry of Wildlife Conservation and Tourism that is responsible for protected area management within the Sudd region.

The Sudd is a Ramsar site, but there are challenges with environmental governance due to the lack of policies, laws, and guidelines related to wetland conservation. Compounding the situation is the lack of information on the wetlands to support decision making. To that end, it is highly recommended that a wetland inventory be undertaken to generate the data and information required.

The Sudd wetland currently has no management plan (MoE, 2018). There is opportunity to build supervisory and regulatory capacity and develop management plans for the protected areas and the entire Sudd wetland system.

According to the (MoEF, 2019), key national legislation for biodiversity management include the National Environmental Protection Bill 2013; South Sudan Water Policy 2007; The Draft Wildlife Bill 2013 and the Wildlife Conservation and Protected Areas Bill 2015; The Water Bill 2013; The National Environment Policy 2015-2025; and the Forests Bill 2009. Draft Policies and plans include: The Draft Sudd Management Planning Framework 2021; The South Sudan Wildlife Conservation and Protected Area Policy (Draft of June 2012). South Sudan also participates in regional and global networks in support of sustainable management of wetland resources such as the Ramsar Convention. Some of the activities that have been undertaken and proposed under this convention are listed verbatim below (MoE, 2018):

- Relevant key stakeholders have been identified and cross-sectoral committee will be established for the Sudd wetland Ramsar site.
- Effectiveness of the Sudd Ramsar site was assessed in 2006 using the Ramsar handbook for the criteria for designation of the wetland as a Ramsar site.
- The local stakeholders and communities are involved in the management of the Ramsar site by encouraging traditional and customary methods of management and conserving wetlands.
- It is planned to:
  - survey, research and assess the ecosystem benefits and services provided by the Sudd wetland Ramsar site.
  - include socioeconomic and cultural values of wetlands as part of the management plan for the Sudd wetland Ramsar site.
  - Establish a communications system to assist the Ramsar site managers (when appointed).

Civil society is actively involved in advocacy and policy relevant research. The Sudd Environment Agency (SEA) was formed in 2019 to advocate for the protection of the Sudd environment with a specific focus on preventing oil pollution. SEA recently spearheaded a new consortium – the Environment and Climate Change Network – to strengthen advocacy. The civil society organizations involved in this consortium include Yo' Care, People Initiative Development Organization, Africa Centre for Research and Development, and the Sudd Environment Agency.

Research as an underpinning necessity for evidence-based policy making and decision making is a growth area in South Sudan. The independently run Sudd Institute conducts research with the aim of encouraging policy conversations, improving the capacity to analyze different scenarios and strategy formulation in the country to support decision making in South Sudan. Two laws – the Southern Sudan Research Council Act 2007 and Kush Institution Act 2008 both enable the establishment of government think tanks for this purpose.

5. Challenges and opportunities for action

Despite the numerous challenges in the Sudd area, the natural resources present a multitude of opportunities to enhance the livelihoods and wellbeing of the people. There are calls for research into environmentally and economically sustainable alternatives to encourage wise use of resources while encouraging the protection and management of the Sudd ecosystem. Agriculture, ecotourism, financing of wetland restoration, modernization of fishing practices and research are some of the areas of opportunity.

Agriculture

Despite the huge economic value of the Sudd, benefits are not directly accruing to people living there. Proposed solutions like agricultural expansion are likely incompatible with wetland preservation. Rice is the main crop grown in the region due to the flooding which is naturally favorable for the cultivation of rice. Millet and maize are also grown. The crop growing season in the Sudd lasts from April till September. The short duration of the rainy season and the erratic distribution of rainfall during the growing period are the main limiting factors for agriculture in South Sudan. Hence, it might be prudent for the GoSS to **consider promoting climate-smart agricultural techniques to improve livelihoods and food security under changing climatic patterns and implementing provisions of the Irrigation Development Master Plan developed in 2015 for improving crop yields.**

Investment in the livestock sector

Cattle, goats, and sheep are the main livestock animals in South Sudan. It is estimated that the total value of goods and services provided by livestock to the South Sudan economy in 2013 was US $3.173 billion (ICPALD), 2016). Livestock are used to provide milk, food and other products. They can be used as cash, or as gifts for instance at weddings and provide income through seasonal farm work or herding. They are a source of wealth and cultural pride and reduce vulnerabilities and enhance household resilience through difficult seasons.

Factors driving poverty in agro-pastoral and pastoral livelihood zones are insecurity, livestock disease, floods and the economy (Cullis, 2021). Disparities in wealth are seen through inequalities in family size, children in school or in employment, land holdings and in livestock. For instance, the more well-off families may own between 100 and 200 times more livestock than those at the bottom of the wealth ladder. About 60-70 of agro-pastoral households and 34 per cent of pastoral households are categorized as poor or very poor (Cullis, 2021).

Poverty is a major limiting factor. It is disempowering, and can lead to food insecurity, ill health, conflict and instability. In fact, conflict has weakened South Sudan's social networks as these are based on livestock-related transactions which are minimal. There has been an increase in the number of poorer households, and this is beyond the capacity of the 'wealthy' social safety nets to support in the form of food gifts among others. It is important that policy **consider investing in the livestock sector given its importance to societal wellbeing** (Cullis, 2021).

Ecotourism

Given the biological diversity and unique landscape, tourism is often put forward as a potential for sustainable development and it is even estimated that a well-managed, high-quality, low volume industry could generate the economy US $600 million per year. However, whilst insecurity reigns, it is difficult to see how the tourism industry could begin to grow. To address this issue, it is recommended that the government **undertake strategic and financial planning for wildlife protected areas so that revenue generated can be utilized to cover some of the costs needed to adequately protect key wildlife areas such as those in the Sudd wetland** (MoEF, 2019).

Financing of wetland restoration

Wetland restoration is a strategy that has been proven to work by supporting livelihoods, creating new or improved ecosystem services, and supporting carbon sequestration. Wetland restoration is listed in South Sudan's second Nationally Determined Contributions (NDC) to United Nations Framework Convention for Climate Change. Not much has been done as the extent of the restorative work has not yet been mapped. As such, it is not possible to assess the scale of the benefits. Undertaking this activity would then allow financial resources to be secured to support implementation.

Wetland reclamation is hard to fund because the benefits are not tangible and are often dispersed. To that end, it is recommended that the GoSS **seeks creative or alternative funding sources such as Payment for Ecosystem Services, an approach where downstream beneficiaries pay for the services.**

Wetland restoration is complex and is compounded by the water politics of the Nile basin. There is value in pushing for a wetland equivalent to the UN Reducing Emissions from Deforestation and Forest Degradation (REDD) programme, which pays for results-based emissions reductions (Darbyshire, 2021).

Modernization of fishing practices

The fishing industry in South Sudan is poorly developed by modern production standards, yet there is opportunity for this industry to improve food security, support livelihoods and income generation, and economic transformation with industrial growth, exports, and job creation leading to significant increases in the Gross Domestic Product (Mimbugbe, 2021).

Fishing in South Sudan is practiced as a complementary seasonal livelihood strategy by pastoralists when they return to the dry season grazing grounds. Despite huge potential, there is lack of support infrastructure, inadequate and inappropriate fishing equipment and difficulty of transportation between production and consumption areas. The fish catch is thus limited to meet the domestic and available market demand. Some of the challenges include inefficient fishing and processing technology which lead to high postharvest losses, lack of organization and skills to scale up their operations, and multiple taxes on dried and smoked fish products. In addition, landing sites are poorly developed and there is lack of cold storage facilities, financing, modern value-added services, quality control and market orientation programs to support the sector. There is **need to modernize and invest in the fish sector**. The following case study from Bor as quoted from OCHA, 2021, highlights the challenges and opportunities in the fishing sector.

Commercial fishing business in Gemeiza along the Nile in the Sudd wetland
Photo credit: *Michael Lopidia, SSNCO*

South Sudan | Improving catch and reducing post-harvest losses for fishing communities in Bor South through knowledge (OCHA, 2021)

"Even with the fertile waters of the White Nile and its tributaries, life-long fisher Deng Abdulai's catch always fell short of providing a sufficient income for his family. Waking at 2:00 a.m. to paddle his heavy dugout canoe, Deng would typically reach his fishing grounds in as many as four hours. Paddling against heavy currents and often spending nights in his canoe in sometimes harsh weather conditions requires resilience, endurance and determination. Despite his efforts, a lack of supplies and the perennial threat of spoilage because of the long voyage back to the community meant Deng struggled to feed and care for his wife, two children and extended family.

With over 1.7 million people dependent on fishing as a source of livelihood, many of South Sudan's fishing communities still lack the capacity to preserve their catch and adequately use available fisheries resources for their economic benefit.

Deng lives in the village of Pariyak in Kolynyang Payam of Bor South County, an area in Jonglei State devastated by floods in 2020 and among the ten counties in South Sudan where food insecurity is extremely dire. While the already vulnerable population saw the destruction of their homes and livelihoods because of the heavy rains, the Nile and its tributaries presented the only means of generating income for many.

The son of a long line of fisherfolk, Deng had learned the essential skills of net-braiding and fishing as a boy when he and his father would use their dugout canoe to go fishing and set nets. In the past, due to constraints and limited knowledge, fisherfolk in this community would land few fish, mostly only enough for family consumption.

In 2017, the Food and Agriculture Organization of the United Nations (FAO) began activities to enhance the production, resilience and sustainability of the agriculture, fisheries and livestock sectors by addressing vulnerabilities that lead to food insecurity and malnutrition. Through the Sustainable Agriculture for Economic Resiliency (SAFER) project funded by the Government of the United States of America through the United States Agency for International Development (USAID), FAO and partners quickly identified communities such as Pariyak to revitalize the fisheries sector and sensitize people on the importance of responsible fishing for increased and sustainable production.

Since activities began, fisherfolk from three states in South Sudan – Jonglei, Lakes and Western Equatoria – received 80 fiberglass canoes, fishing kits, bags and tarpaulins. With the onset of heavy rains culminating in devastating floods, the project expanded its fisheries focus and by June 2021 had provided over 5,700 fishing twines and 2,750 fishing hooks to 570 fisherfolk belonging to 18 fishing groups.

Encouraged by FAO staff, Deng and his community of fishers organized themselves into the 30-member Pariyak Fishing Group. Although the group had been fishing together prior to the intervention, the project formalized it to establish a network of support, promote savings, disseminate knowledge through trainings and provide fishing inputs.

Overall, the trainings have had great impact on the group's success and the lives of its members, whether through newfound marketing knowledge or new technical skills. For instance, while many in the group had preexisting knowledge on net making, FAO offered additional techniques including adjusting the size of the nets to increase a catch.

Deng describes how his group constructed a fish smoking oven and applies the techniques they learned to safeguard their stock. "The trainings have drastically improved our catch. Now that we know how to preserve our fish through smoking and drying, we're able to maintain the quality and more easily sell to traders."

The Pariyak Fishing Group is one of many in Jonglei that have taken advantage of the high waters to increase their catch and income, utilizing the three fiberglass canoes and fishing kits supplied by FAO. Importantly, the group maintained their profits and increased catch after direct support slowed. On average, the fishing groups in Bor catch about 100-150 fish per day, earning them up to SSP 150 000 – the equivalent of around USD 150 – each day. Now the members can buy sorghum, the staple crop of the area, for home consumption, medicine, to pay for school fees and to cover other basic expenses.

With the slow increase in water levels around the tributaries and plains making fish more available, the delivery of inputs from FAO allowed fisherfolk to catch more. "Now, with our increase in earnings we are hoping to buy a motorboat, which will allow us to cover even more area and stay out later without having to paddle against the strong current," said Deng.

Through their determination and ability to absorb and bounce back from severe shocks, fishing groups like Deng's in Pariyak demonstrate the resilience achieved by many vulnerable people (OCHA, 2021)".

Further research by the international scientific community

Significant knowledge gaps exist, and it is critical to **address the need for further research into the various social, cultural, environmental, and economic aspects of the Sudd wetland.** Some of the areas for inclusion on the research agenda include (Darbyshire, 2021):

- The functioning of the Sudd ecosystems, hydrological processes, impact of climate change and potential sources and sink of GHGs.
- The role of the Sudd as a regional rainfall modulator
- Hydrological modelling to support analysis of the impacts of reviving the Jonglei canal project
- Cultural studies to determine possible impacts on communities and livelihoods from construction of the Jonglei Canal and draining of the Sudd. These would inform the development of a Sudd wetland management plan (MoE, 2018).
- Studies to understand the GHG dynamics of the Sudd. These are required because a supporting opinion for construction of the Jonglei canal is to mitigate emissions from oil expansion and to reduce natural emissions of methane. However, not enough is known about the Sudd's carbon storage or sink capabilities. If the wetlands are a carbon sink, and degraded areas can be restored, there is potential for compensation as a carbon store like ecosystem compensation services under REDD (Darbyshire, 2021).
- Research to examine the effect of cultivation duration and flooding regimes on soil seed bank species richness, diversity, and density and composition (Easete et al., 2021). Soil seed banks are important for regeneration of degraded wetlands ecosystems.
- Biodiversity assessment to document the species richness and endemism of terrestrial, aquatic and underground biodiversity. The Migration and Ecology of the white eared kob (WEK), and Avian migration flyways and roosting spots.

Climate finance

Climate finance relates to the money which needs to be spent on a whole range of activities which will contribute to slowing down climate change and which will help the world to reach the target of limiting global warming to an increase of 1.5°C above pre-industrial levels. To reach this goal, the world needs to reduce its net greenhouse gas emissions to practically zero by 2050; the phrase net-zero is also heard frequently in the context of financing climate action. Initiatives that must be financed to reach net-zero include those which reduce emissions of harmful gasses as well as enhancing or protecting the natural processes which capture those gasses.

There are several UN-backed international climate funds, for example:

- **Climate Investment Funds (CIFs):** The $8 billion fund "accelerates climate action by empowering transformations in clean technology, energy access, climate resilience, and sustainable forests in developing and middle-income countries."
- **Green Climate Fund (GCF):** Set up by the UNFCCC in 2010, GCF is the world's largest dedicated climate fund, mandated to support mitigation and adaptation action equally in developing countries.
- **Adaptation Fund (AF):** The fund has committed some $830m since 2010 to help vulnerable communities in developing countries adapt to climate change
- **Global Environment Facility:** GEF aims to "catalyze transformational change in key systems that are driving major environmental loss", in particular energy, cities and food.
- **UN-REDD:** Three UN agencies (UNEP, UNDP and FAO) teamed up a decade ago to protect forests, a "pre-eminent nature-based solution to the climate emergency".
- **Clean Technology Fund (CTF):** The $5.4bn is "empowering transformation in developing countries by providing resources to scale up low carbon technologies" (UN, 2021).
- In addition, in the **voluntary carbon market**, carbon credits are purchased by companies or individuals to help reduce their impact on climate change. Companies may purchase carbon credits to become "carbon neutral" or "green" companies. Individuals may purchase credits to offset their emissions from activities such as flying. To curb climate change, multi-national companies like Microsoft and Google are setting ambitious goals to achieve carbon neutrality and the Voluntary Carbon Market (VCM) is helping them to do so. (GCF, 2022). **Considering the significant carbon sequestration potential of Sudd wetland, VCM may provide a significant opportunity to GoSS, but major challenges remain in accessing such a market.**

Livestock in Toich in the Sudd
Photo credit: *Michael Lopidia, WCS*

6. Key recommendations

- **Implement obligations under the Ramsar Convention.**
- **Employ a Resilient Management Strategy combining action, science, and learning from best practice in the Sudd:** Given the value of the natural resources and their contribution to ecosystem health and human wellbeing such as the pastoralists, livestock and other benefits accrued from the Sudd wetland, the GoSS should promote policies that maintain the healthy functioning of the Sudd wetland by protecting and restoring the goods and services they provide. Such policies might include designating additional protected area status, for example, the suggested UNESCO World Heritage Site listing. Implementing this recommendation would require resilient management strategies that can adapt to shifting geo-politics, changes in water demand and the impacts of climate change.
- **Carry out Environmental and Social Impact Assessments (ESIA) of infrastructure projects:** The requirements under the Ramsar Convention stipulate that the government does everything in its power to maintain the integrity of the Sudd ecosystem. Rigorous environmental and social impact assessments based on credible scientific information should be conducted before embarking upon infrastructure projects. Such ESIAs should consider impacts to livelihoods, security issues, population displacement and degradation of ecosystem services, among others.
- **Examine the policies, practices and impacts of the possible revival of the Jonglei Canal:** This recommendation should be based on the results of an ESIA with rigorous scientific data collection and analysis. If pursued, GoSS should adhere to the core principle of '*water for South Sudanese people and ecosystems first*' before releasing excess water to downstream countries. There is also need to mitigate flood intensity by negotiating with the upstream riparian countries.

  Water management in South Sudan should account for the following issues:

  - Water for ecosystem services
  - Water for electricity generation
  - Water for irrigation
  - Management of excess water to reduce flooding.
- **Deploy an early warning system for flood and drought:** According to recent IPCC scenarios, more seasonal flooding and drought are likely to occur in the region in future. Early warning systems (EWS) are key elements of climate change adaptation and disaster risk reduction to avoid or reduce the damages caused from such hazards. To that end, GoSS should strengthen capacity for drought and flood Early Warning Systems through an improved hydro-meteorological monitoring network and timely communication to community level. There is opportunity to leverage ongoing initiatives

A water intake point for a demonstration farm in Bor, Jonglei State
Photo credit: *Eugene Apindi Ochieng/EPI*

like the USAID Famine Early Warning Systems Network (FEWS NET), FAO Global information and early warning system (GIEWS), and the OCHA Anticipatory Humanitarian Action framework, among others.

Strengthening of the hydro-meteorological system should include, among others, Automatic Weather Station, Cup Counter Anemometer, Pyranometer for Shortwave and global Radiation, Rain Gauge, Rainfall Recorder and Logger, Standard Weather Station, Stream gauges, Evaporation Recorder, Wind Vane and Temperature Humidity Recorders. Capacity building for these equipment will also be required.

The GoSS should negotiate and enter bilateral agreements for sharing hydro-meteorological information with upstream countries of the Nile River such as Uganda.

- **Improving flood control measures and recovering local economies:** The buildup of biomass in the Sudd and along the White Nile has been clogging the waterways and disbursing the water across all the tributaries and their surrounding area. Flood control measures, like dykes, dredging, removal of biomass for clearing water channels, small canals and irrigation channels, reclamation of land, should be considered to support local fishing and agriculture. Dredging will not only help the streamflow, but also improve water navigation. Areas suitable for deep water or shallow water dredging should be identified after ESIAs. Agriculture production in rainfed areas could be improved by implementing the proposed Irrigation Master plan of 2015.
- **Reduce uncertainties by promoting scientific research:** The Sudd wetland has not attracted the attention of the global research community due to conflict and its remote location in South Sudan. As indicated in sections of this report, there are many research areas that require attention. These include spatial extent and variability of the Sudd, water availability, evapotranspiration rate, impacts of climate change, impact of Sudd on regional climate, extent of peatlands, carbon sequestration potential, cultural and ecosystem dynamics. The GoSS, together with development partners such as UNEP, should endeavor to put the Sudd on the global research agenda. Results would be important for national level decisions on the wise use of the Sudd wetland ecosystem for the future security, sustainability, and stability of South Sudan.

Researchers measuring a peat core extracted from the Sudd wetland
Photo credit: *John Ater, MoEF*

References

COA. (2012). The Role of Wetlands in the Carbon Cycle. Issues Paper. Canberra : e Department of Sustainability, Environment, Water, Population and Communities. Commonwealth of Australia (COA). Retrieved from https://www.awe.gov.au/sites/default/files/documents/wetlands-role-carbon-cycle.pdf

Cullis, A. (2021). Understanding the Livestock Economy in South Sudan - Field study findings. UK Aid. Retrieved March 14, 2022, from file:///D:/Documents/Sudd%20Wetlands%202021/Field-Report.pdf

Darbyshire, E. (2021, November). Is South Sudan's Sudd wetland at a fork in the road? Conflict and Environment Observatory. Retrieved November 12, 2021, from https://ceobs.org/report-is-south-sudans-sudd-wetland-at-a-fork-in-the-road/

Di Vittorio, C., & Georgakakos, A. (2018, January). Land cover classification and wetland inundation mapping using MODIS. Remote Sensing of Environment, 204, 1-17. Retrieved July 15, 2021, from https://www.sciencedirect.com/science/article/abs/pii/S0034425717305114

Di Vittorio, C., & Georgakaos, A. P. (2021). Hydrologic Modeling of the Sudd Wetland using Satellite-based Data. Journal of Hydrology: Regional Studies, 37, 20. doi:https://doi.org/10.1016/j.ejrh.2021.100922

Easete, J., Bongo, A., Lado, T., Bojoi, T., & Busulwa, H. (2021, March 21). Natural vegetation regeneration from soil seed banks in the cultivated edges of Sudd wetlands in Juba, Southern Sudan. East African Journal of Science, Technology and Innovation, 2(2), 19. Retrieved July 16, 2021, from https://eajsti.org/index.php/EAJSTI/article/download/214/37/1493

ESA. (2021). Worldwide land cover mapping. Retrieved January 25, 2022, from ESA: https://esa-worldcover.org/en

FEWS NET. (2018). Livelihoods Zone Map and Descriptions for the Republic of South Sudan (updated), August 2018. Washington, DC: FEWS NET. Retrieved February 6, 2022, from https://reliefweb.int/sites/reliefweb.int/files/resources/Livelihoods%20Zone%20Map%20and%20Descriptions%20for%20South%20Sudan.pdf

FoA. (2021). The Sudd. Retrieved July 14, 2021, from Welcome to South Sudan: https://fortuneofafrica.com/southsudan/the-sudd/

GCF. (2022). What is the Voluntary Carbon Market? Global Carbon Fund (GCF). Retrieved March 6, 2022, from https://globalcarbonfund.com/carbon-news/what-is-the-voluntary-carbon-market/

Gowdy, J., & Lang, H. (2016). The Economic, Cultural and Ecosystem Values of the Sudd Wetland in South Sudan: An Evolutionary Approach to Environment and Development. Nairobi: United Nations Environment Programme (UNEP)I. Retrieved July 14, 2021, from https://evolution-institute.org/wp-content/uploads/2016/09/20160913_ei_south-sudan_low-res.pdf

GPI. (2016). What is the Global Peatlands Initiative? Retrieved March 22, 2022, from Global Peatlands Initiative (GPI): https://www.globalpeatlands.org/

Hickman, J. E., Andela, N., Dammers, E., Clarisse, L., Coheur, P.-F., Van Damme, M., . . . Bauer, S. E. (2021, November 16). Changes in biomass burning, wetland extent, or agriculture drive atmospheric NH3 trends in select African regions. Atmos. Chem. Phys., 21(21), 16277–16291. doi:https://doi.org/10.5194/acp-21-16277-2021

ICPALD). (2016). The Contribution of Livestock to the South Sudan Economy. IGAD Center for Pastoral Areas & Livestock Development (ICPALD). Retrieved from https://www.icpald.org/wp-content/uploads/2019/08/Policy-Brief-on-the-Contribution-of-Livestock-to-South-Sudan-National-GDP-Jan-2016.pdf?msclkid=8f7c96f0b27811ec883546ea86312608

IPCC, 2022: Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. In Press.

Lunt, M. F., Palmer, P. I., Feng, L., Taylor, C. M., Boesch, H., & Parker, R. J. (2019, December 11). An increase in methane emissions from tropical Africa between 2010 and 2016 inferred from satellite data. Atmos. Chem. Phys, 19, 14721–14740. doi:https://doi.org/10.5194/acp-19-14721-2019

McGuinnes, S., & Becker, R. (2019). Understanding Groundwater-Surface Water Hydrology of the Sudd Wetland, South Sudan, Using Monthly GRACE Anomalies and MODIS NDVI/NDWI Time series. American Geophysical Union. Retrieved July 17, 2021, from https://ui.adsabs.harvard.edu/abs/2019AGUFM.H43M2244M/abstract

Mimbugbe, M. (2021, July 14). Protecting biodiversity to boost South Sudan's economy. InfoNile. Retrieved March 6, 2022, from https://www.infonile.org/en/2021/07/protecting-biodiversity-to-boost-south-sudans-economy/

MoE. (2018). National report to Ramsar COP13 - Republic of South Sudan. Juba: Ministry of Environment (MoE), South Sudan. Retrieved July 14, 2021, from https://www.ramsar.org/sites/default/files/documents/library/cop13nr_south_sudan_e.pdf

MoEF. (2019). Republic of South Sudan National Biodiversity Strategy and Action Plan (2018-2027). Nairobi: United Nations Environment Programme (UNEP). Retrieved March 14, 2022, from https://www.cbd.int/doc/world/ss/ss-nbsap-01-en.pdf

MoEF. (2021). South Sudan's Second Nationally Determined Contribution. Juba: South Sudan Ministry of Environment and Forestry (MoEF). Retrieved March 11, 2022, from https://www4.unfccc.

int/sites/ndcstaging/PublishedDocuments/South%20Sudan%20Second/South%20Sudan%27s%20Second%20Nationally%20Determined%20Contribution.pdf

Mohamed , Y. A., Hurk, B. v., Savenije, H., & Bastiaanssen, W. (2005). Impact of the Sudd wetland on the Nile hydroclimatology. Water Resources Research, 41(8). doi:https://doi.org/10.1029/2004WR003792

Mohamed, Y. A. (2006). The Nile Hydroclimatology: Impact of the Sudd Wetland. CRC Press. Retrieved July 16, 2021, from https://www.routledge.com/The-Nile-Hydroclimatology-Impact-of-the-Sudd-Wetland/Mohamed/p/book/9780415384834

Mohamed, Y., & Savenije, H. (2014, April). Impact of climate variability on the hydrology of the Sudd wetland: signals derived from long term (1900–2000) water balance computations. Wetlands Ecol Manage, 22, 191-198. doi:10.1007/s11273-014-9337-7

MoP. (2020). South Sudan Oil. South Sudan Ministry of Petroleum (MoP). Retrieved January 30, 2022, from https://mopaudits.gov.ss/south-sudan-oil-and-gas-industry/

NBI. (2019). Peatlands study findings to help Nile Basin countries improve on climate change mitigation. Nile Basin Initiative. Retrieved January 25, 2022, from https://nilebasin.org/~nileba5/new-and-events/304-peatlands-study-findings-to-help-nile-basin-countries-improve-on-climate-change-mitigation#:~:text=The%20most%20important%20concentration%20of%20peatlands%20in%20the,total%20carbon%20stock%20of%20the%20ent

NBI. (2020). Sudd Wetland Economic Valuation of Biodiversity and Ecosystem Services for Green Infrastructure Planning and Development. Nile Basin Initiative (NBI). Retrieved July 14, 2021, from https://nilebasin.org/index.php/information-hub/technical-documents/103-sudd-wetland-economic-valuation-report-south-sudan-2020/file

NBI. (2021). Nile basin wetlands of transboundary significance: Inventory, baseline study and framework management Plan with a nested case study on the Sudd. Nile Basin Initiative. Retrieved January 25, 2022, from https://www.hydroc.de/nile-basin-wetlands-of-transboundary-significance-inventory-baseline-study-and-framework-management-plan-with-a-nested-case-study-on-the-sudd/

NBI. (n.d.). Sudd Wetland. Retrieved January 25, 2022, from Nile Basin Initiative (NBI): https://www.nilebasin.org/wetlands/portfolio-item/sudd-wetlands/

OCHA. (2021, July 14). South Sudan ⊠ Improving catches and reducing post-harvest losses for fishing communities in Bor South through knowledge. (United Nations Office for the Coordination of Humanitarian Affairs (OCHA)) Retrieved March 14, 2022, from South Sudan: https://reliefweb.int/report/south-sudan/south-sudan-improving-catches-and-reducing-post-harvest-losses-fishing

OCHA. (2022, February). South Sudan Humanitarian Snapshot. (United Nations Office for the Coordination of Humanitarian Affairs (OCHA)) Retrieved March 14, 2022, from South Sudan: https://reliefweb.int/sites/reliefweb.int/files/resources/south_sudan_humanitarian_snapshot_february_0.pdf

Origins Safaris. (2021). Witness the second largest migration - The Sudd Migration - with Origins Safaris. Retrieved from Origins Safaris: https://originsafaris.com/2533-2-2-4-2-2-2-2-2-2-2-2-2-2-2-2-2-2-2-4-2-2/

Pandey, S., Houweling, S., A., L., Borsdorff, T., Tsivlidou, M., Bloom, A., . . . I., A. (2021, January 22). Using satellite data to identify the methane emission controls of South Sudan's wetlands. Biogeosciences, 18, 557-572. doi:https://doi.org/10.5194/bg-18-557-2021

Riak. (2003). Sudd area as a Ramsar site: Biophysical features. Nairobi: United Nations Environment Programme. Retrieved January 28, 2022, from https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fpostconflict.unep.ch%2Fsudanreport%2Fsudan_website%2Fdoccatcher%2Fdata%2FJuba%2520Workshop%2520Papers%2FSudd%2520paper.doc&wdOrigin=BROWSELINK

Rutagwera, P. (2019). Hydrology of the Nile. Nile Basin Org. Retrieved March 11, 2022, from https://nilebasin.org/index.php/media-center/infographics/75-nbi-hydrology/file

Rutagwera, P. (2021). The real value of Nile Basin Wetlands. Nile Basin Initative (NBI). Retrieved March 12, 2022, from https://nilebasin.org/index.php/media-center/infographics/132-the-real-value-of-nile-basin-wetlands/file

Ruuskanen, C. (2021). Wetland dynamics and conflict in the Sudd. Conflict and Environment Observatory. Retrieved November 12, 2021, from https://ceobs.org/land-cover-dynamics-and-conflict-in-the-sudd-wetland/

Trisos, C. H., Adelekan, I. O., & Totin, E. (2022). Chapter 9: Africa. In IPCC, IPCC WGII Sixth Assessment Report. Intergovernmental Panel on Climate Change (IPCC). Retrieved from https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FinalDraft_Chapter09.pdf

UN. (2021, June 27). https://news.un.org/en/story/2021/06/1094762#:~:text=Broadly%20speaking%2C%20climate%20finance%20relates,C%20above%20pre%2Dindustrial%20levels. UN news. Retrieved March 14, 2022, from https://news.un.org/en/story/2021/06/1094762#:~:text=Broadly%20speaking%2C%20climate%20finance%20relates,C%20above%20pre%2Dindustrial%20levels.

UNEP. (2018). South Sudan First State of Environment and Outlook Report. Nairobi: United Nations Environment Programme (UNEP). Retrieved March 22, 2022, from https://wedocs.unep.org/bitstream/handle/20.500.11822/25528/SouthSudan_SoE2018.pdf?sequence=1&isAllowed=y

UNEP-WCMC. (2022, February). South Sudan. Retrieved February 6, 2022, from Protected Area Profile : https://www.protectedplanet.net/country/SSD

UNESCO. (2017). Sudd wetland. United Nations Educational, Scientific and Cultural Organization (UNESCO). Retrieved July 14, 2021, from https://whc.

unesco.org/en/tentativelists/6276/

UNOSAT. (2022). Satellite detected water extents between 23 and 27 February 2022 over South Sudan - Imagery Analysis: 23 to 27/02/2022 Published 02/03/2022 V1. United Nations Satellite Centre (UNOSAT). Retrieved from https://reliefweb.int/map/south-sudan/satellite-detected-water-extents-between-23-and-27-february-2022-over-south-sudan

USAID. (2016). Climate Change Risk Profile. Washington, DC:United States Agency for International Development (USAID).Retrieved May 10, 2022, from https://www.climatelinks.org/sites/default/files/asset/document/2016%20CRM%20Fact%20Sheet%20-%20South%20Sudan_0.pdf

USDA. (2022, March 14). Near Real Time products with datum based on a single satellite overpass (1 day). Retrieved March 14, 2022, from Global Reservoirs and Lakes Monitor (G-REALM): https://ipad.fas.usda.gov/cropexplorer/global_reservoir/

WFP. (2021). WFP South Sudan. Country Brief December 2021. Juba: World Food Programme (WFP). Retrieved from https://reliefweb.int/sites/reliefweb.int/files/resources/WFP%20South%20Sudan%20December%20Country%20Brief%20_0.pdf