WEATHERING RISK

DINDER NATIONAL PARK, SUDAN

Climate Impact Profile

Sam Geldin

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adelphi RESEARCH

AUTHOR
Sam Geldin (Climatepedia)

CONTRIBUTORS
Yosr Khedr (adelphi research)
Hector Camilo Morales-Munoz (adelphi research)
Lukas Rüttinger (adelphi research)
Alexandra Steinkraus (adelphi research)

COVER IMAGE
Odile Stabon

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Alt-Moabit 91, 10559 Berlin, Germany
+49 (030) 8900068-0
office@adelphi-research.de
www.adelphi-research.de/en

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Design & Layout: Odile Stabon

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Summary for policymakers

Dinder National Park (DNP) is located in southeastern Sudan, and encompasses areas of Gedaref, Sennar and Blue Nile states. It is one of the most biodiverse regions in Sudan, boasting distinct ecosystems, rare species and outstanding wetlands. Two rivers, the Dinder and the Rahad, run through the national park. Originating in the Ethiopian Highlands, both rivers flow west and join the Blue Nile River in Sennar State. Their basins cover approximately 35,000 km² and 42,500 km², respectively. This profile provides an overview of observed and projected climate trends for near-term (2020–39), medium-term (2040–59) and long-term (2060–79) time periods across the three Sudanese states. Projected trends rely on two climate change scenarios, a lower-emissions SSP1-2.6 scenario and a higher-emissions SSP3-7.0 scenario. The region and the communities living in the park's buffer zone are particularly vulnerable to climate variability. Southeastern Sudan, including DNP, has a seasonally dry tropical climate. Over the last 50 years, the region has become warmer and drier, with increases in both maximum and minimum overall temperatures, and a significant decrease in annual precipitation across the entire region, with particularly high interannual variability.

Climate Trends and Extreme Weather

Temperature

Southeast Sudan faces significant temperature increases under both high-emissions (SSP3-7.0) and low-emissions (SSP1-2.6) scenarios starting in the near term (2020–39). Under the SSP3-7.0 scenario, annual mean temperature in Sennar State increases uniformly by a best estimate of 0.62ºC (0.33ºC and 1.01ºC possible) over the near term, 1.46ºC (0.85ºC and 2.03ºC possible) over the medium term and 2.29ºC (1.42ºC and 3.27ºC possible) over the long term. While annual mean temperatures in Blue Nile and Gedaref states remain broadly similar to those in Sennar State under both scenarios, Gedaref State faces the largest mean temperature increase over the long term. In Sennar State, the number of hot, humid days (Heat Index days with maximum temperatures > 35ºC) and warm tropical nights (minimum temperatures > 26ºC) increase dramatically before and after mid-century at rates similar to the long-term increase in mean temperatures in Gedaref State under high-emissions scenarios. The highest increases occur near the beginning (May–June) and end (October) of the rainy season. High combined heat risks are projected across all time periods and scenarios in Gedaref and Sennar states, particularly in northern and western areas of DNP.

Precipitation

Southeast Sudan's median annual precipitation is projected to rise, particularly during the peak rainy season and late autumn, though climate models show mixed agreement on the direction and intensity of these changes in the near to medium term. Under the high-emissions scenario (SSP3-7.0), Sennar State could see its largest monthly increase in November, with +24% (-17% and +95% possible) in the near term, +33% (-12% and +131% possible) in the medium term and +53% (-8% and +197% possible) in the long term. These dramatic increases suggest a shift toward later precipitation peaks in the rainy season. While annual and seasonal precipitation amounts under the two scenarios increase on average, high interannual variability suggests more frequent and intense dry spells may also occur. These changes highlight the importance of preparing for greater variability in seasonal, annual and interannual rainfall patterns.

Floods

The Dinder and Rahad river systems face increasing flood risk along certain portions of their catchment areas, due in part to high inherent climate variability, but models display mixed agreement under a high-emissions scenario (SSP3-8.5) and under a lower emissions scenario (SSP2-4.5) in the near and medium terms. Flash flooding along the Rahad River could reach depths of up to 80 cm during the peak months of the rainy season. Within the park, the middle section of the Dinder River already faces an extremely high baseline risk of riverine flooding upstream of its confluence with the Khor Gelagu, and high baseline risk of riverine flooding downstream of its confluence with the Khor Gelagu. Similarly, the Khor Kenana in western DNP faces an extremely high risk, while the Rahad River in northern DNP faces a high flood risk, with overflow events potentially reaching depths of up to 3 m.

Droughts

DNP faces increasing future drought risk due to higher evaporation rates from rising temperatures, and more frequent and intense interannual changes in rainfall, even though median annual precipitation is projected to rise. The Dinder and Rahad river basins have historically experienced frequent severe droughts. Under warming climate scenarios, drought conditions are expected to remain at least moderate in the near and medium term, with very dry periods and stronger drought impacts alternating with more intense wet periods. This pattern is driven by greater climate variability associated with El Niño and positive Indian Ocean Dipole phases. Medium-high drought risk is projected to persist along the Khor Kenana in western DNP and the Dinder River downstream of its confluence with the Khor Gelagu in northern DNP (Sennar State). However, much of the Dinder and Rahad river catchments face at least medium-high interannual water supply variability beginning in the near term under both emissions scenarios. This acts as one of the most indicative metrics of future water shortages in DNP. Water stress during the dry season is expected to remain particularly high along the Khor Kenana and Khor Abu Al-Hasan to the north of DNP, beginning in the near term under both low and high-emissions scenarios.

Projected Sectoral Impacts

Ecosystem

DNP's rich biodiversity is increasingly threatened by habitat loss, degradation and fragmentation driven by rising temperatures, and greater competition for resources resulting from more frequent and extreme variability in rainfall. Projected increases in maximum temperatures are expected to harm individual species and accelerate habitat loss by increasing evapotranspiration. Changes in the timing, amount and variability of rainfall also impact habitat quality and species population sizes. Climate models indicate that more intense peak rainy seasons and increased late-season rainfall will reduce the ability of wetlands (mayas) to absorb excess water, while repeated cycles of droughts and flooding will accelerate wetland sedimentation and degradation. These impacts are especially pronounced along the park's main seasonal tributary, the Khor Gelagu. At the same time, increasingly variable precipitation and altered hydrological patterns are likely to further weaken ecosystem resilience. More frequent and severe floods and droughts threaten the park's ecosystem services and compound the harmful effects of human activities, such as deforestation, land-use change, overharvesting and overgrazing, all of which contribute to ongoing erosion and habitat degradation.

Human Health

Climate-related health risks, including heat stress, vector-borne diseases and water-borne diseases, are generally projected to worsen over time. Combined heat risks increase most at the beginning and end of the rainy season under both emissions scenarios. Heat-related mortality, which significantly increases above 31°C, disproportionately affects outdoor labourers in more densely settled irrigated areas along the Rahad River (DNP transitional zone, Gedaref State) and downstream of the Dinder and Blue Nile rivers outside DNP (Sennar State). Warmer tropical nights raise heat-related mortality and morbidity rates, especially when combined with high daytime temperatures and other local environmental factors (e.g., loss of trees) and individual health vulnerabilities. Future projected temperature increases coupled with extreme precipitation variability shift the timing, intensity, and spatial extent of southeast Sudan's vector-borne (e.g., malaria, Rift Valley Fever, dengue, leishmaniasis) and water-borne disease risks over the near and medium term. Water-borne diarrhoeal diseases such as cholera pose increasing risks to southeast Sudan, due to larger projected seasonal peaks in extreme precipitation (i.e., late rainy season) and warmer temperatures that support bacteria growth. Conflicts tend to further increase vector-borne and water-borne disease risks, particularly where basic services and health care infrastructure deteriorate and displacement is widespread.

Livestock-Related Value Chains

Rising risks from extreme heat, floods and droughts are expected to significantly threaten livestock in the DNP region by 2050. The level of risk varies, with different impacts on nomadic and semi-nomadic herders compared with those engaged in more settled agropastoral practices. Heat stress from Heat Index days above 35°C and tropical nights above 26°C directly harms some livestock breeds, and reduces pasture quality and water availability, both of which are essential for livestock survival. These pressures are particularly severe in Gedaref and Sennar states, both of which supported more than four million livestock animals in 2017. Livestock in Sennar State are especially vulnerable to the combined impacts of heat, flooding and drought, while Gedaref State also faces substantial risk.

Agriculture-Related Value Chains

By mid-century, extreme heat, flooding and drought are projected to disrupt crop production, agricultural labour, distribution and trade across southeastern Sudan. The severity of these impacts will considerably depend on interannual changes in precipitation. Rising minimum and maximum temperatures are expected to reduce optimal crop growing conditions, for example, by shortening the growing seasons (June to October) for key crops, such as sorghum and sesame. Under both high and low-emissions scenarios, southeastern states will regularly exceed the temperature thresholds for the successful cultivation of sorghum, sesame and millet, likely leading to declining yields. Meanwhile, more frequent and intense riverine and flash floods are already causing sudden, large-scale crop losses, as well as damage to settlements and critical infrastructure, which is projected to continue in the near term. Irrigated crops tend to perform better than crops relying solely on rainfall, due to the increasing variability and unpredictability of precipitation. Furthermore, climate-related hazards, particularly flooding, also disrupt transport routes and limit access to markets, particularly in areas with high flood risk.

Forest and Non-Forest Timber Product Value Chains

Climate extremes are likely to intensify unsustainable practices such as overgrazing, excessive harvesting and illegal tree cutting. Non-forest timber products are particularly vulnerable to these added climate pressures, with the greatest risks identified in Blue Nile State and, to a lesser extent, Sennar State. In Sennar State, extreme heat and unpredictable rainfall pose the most significant threats to harvesters of non-forest timber products, while Gedaref State also faces considerable challenges. Importantly, the impacts of climate change are unevenly distributed. Vulnerable communities are disproportionately affected by drought, which compounds existing pressures from environmental degradation and ongoing civil conflict.

Human Displacement

Climate-related impacts threaten to exacerbate already high levels of conflict-driven internal displacement. By the end of 2024, conflict-driven internal displacement affected 11.6 million countrywide, the largest figure globally. In Sennar State, the current average annual displacement rate linked to flooding already exceeds 1% of the population, or an estimated 21,000 people, and is likely to rise as extreme rainfall events become more frequent and severe. Droughts and precipitation variability also contribute to large-scale involuntary migration. These pressures interact with conflict dynamics, worsen food and water scarcity, undermine livelihoods and increase natural resource competition. Disaster- and conflict-driven internal displacement pose ongoing threats to DNP and surrounding communities, especially to women and children. Areas near converted or abandoned agricultural land, particularly along migratory corridors, may become conflict hotspots in the vicinity of DNP.

Overview of Dinder National Park Protected Area[1]

DNP is situated along Sudan's border with Ethiopia, and spans Blue Nile, Sennar and Gedaref states. It is considered one of Sudan's most significant protected areas, as it is well known for its network of permanent and seasonal wetlands, known as mayas. The park is home to rare wildlife and diverse ecosystems, making it ecologically and geophysically unique within Sudan.

Situated in the southeast of Sudan near Ethiopia, DNP's unique position places it at the intersection of three Sudanese states, Blue Nile, Sennar and Gedaref. The majority of DNP lies within Sennar State, forming the core and largest portion of the protected area. Gedaref State encompasses a significant, though smaller section of the park along its eastern edge, while Blue Nile State contains only a small fraction in the southern tip. Sennar State is notable for its extensive agricultural landscapes and mechanised agricultural projects, which border and influence the park's ecosystem dynamics. Gedaref State has the largest population of the three states, and contains most of the villages in and around the park's buffer zone. Meanwhile, Blue Nile State provides vital water resources and fertile clay soils that support the park's biodiversity.

DNP is among Africa's oldest national parks. Established in 1935 with an area of 6,330 km^2, UNESCO designated DNP a Biosphere Reserve in 1974, integrating local communities into conservation efforts through buffer zones that allow sustainable human activity while protecting natural habitats. In 1981, the park was expanded to over 10,000 km^2 to include wildlife corridors and ecosystems, which brought 10 villages within its boundaries. This expansion affected local livelihoods, limiting access to farm and grazing land, and increased pressure on the park's resources. Currently, local communities are permitted to live in and access the park's buffer zone, which comprises almost 26% of its total area, to carry out sustainable livelihood activities. Beyond the buffer zone lies the transition zone, covering 21% of the park's area and extending 5 km from its boundaries, including along the Rahad River (Gedaref State) and the southern border with Blue Nile State, where nearby villages and livestock herders are concentrated.

DNP contains three distinct ecosystems, each supporting unique plant and animal life, which collectively frame the park's biodiversity. The mayas are particularly valuable for scientific research and conservation, regulating water in both dry and rainy seasons, supporting climate moderation, and preserving native flora and fauna. This ecological richness is partly due to the park's position at the crossroads of the Ethiopian Highlands and the Saharan-Sudanian biomes. DNP supports wide biodiversity, including elephants, hippos, Tora hartebeest and Nile crocodiles. During the dry season, the park hosts large populations of these species, though numbers drop in the rainy season as animals such as tiang, reedbuck, waterbuck, roan antelope, oribi and ostrich migrate out. The park is also a haven for rare birds, such as the Kori bustard and Egyptian goose.

Human settlement in the Dinder region has a long history, with estimates placing the population at around 100,000 across 34 villages. The population is diverse, with significant representation from western Sudanese, Arab, West African and Nilotic tribes. The Maganu Mountain Community residing within the park is mainly composed of the Hamaj, Funj, Gumuz and Abu Ramala groups. Migration to the region was largely driven by agricultural expansion and land registration policies, attracting groups from West Africa and western Sudan, such as the Masaleet, Falata, Hausa and Rezaigat communities.

Agriculture, particularly rainfed and *gerif* cultivation, is the main livelihood for local communities, but is highly vulnerable to rainfall variability. Households in Ar Rahad locality (Gedaref state) typically farm 19 feddans, while those in the village of Maganu (Blue Nile state) manage about five, mainly growing dura, millet and sesame. Animal husbandry is also important, with both pastoralist and sedentary communities relying on livestock for their livelihoods.

Observed Climate

Several key factors drive seasonally dry tropical climate patterns across Sudan's southeast region encompassing DNP, including: **(1)** seasonal movement of the Intertropical Convergence Zone; **(2)** the wind influences of cool, dry northeasterlies from January to March and moist southwesterlies from May to October; and **(3)** El Niño-Southern Oscillation and Indian Ocean Dipole phenomena, associated with extreme wet and dry periods interannually.[2]

Gedaref, Sennar and Blue Nile states all possess similar average annual mean temperatures of 28–29°C (see **Figure 1a**). The hottest mean temperatures of 32–33°C occur in April and May before the onset of the rainy season, with average minimum temperatures of 24–26°C and hot average maximum temperatures of 40–42°C. Temperatures also moderately increase near the end of the rainy season. The coolest temperatures (mean of 26°C, minimum of 16–17°C and maximum 35°C) occur in January during the dry season.

Since DNP lies along the boundary between low-rainfall savanna in the northwest and higher-rainfall savanna in the southeast**,** average annual precipitation varies across the region. In Gedaref and Sennar states, to the north and centre of the park, annual precipitation averages less than 600 mm, while in Blue Nile State to the south it exceeds 800 mm. The Intertropical Convergence Zone, a global band of low-pressure precipitation that migrates seasonally based on the overhead angle of solar radiation, exerts a year-round influence. From January to March, the Intertropical Convergence Zone migrates furthest south and cool, dry northeasterly winds dominate. The onset of the rainy season begins around May, as moist southwesterly winds begin to dominate and the Intertropical Convergence Zone migrates northward, peaking around August, before swiftly moving southward from September. This rainy season is shorter and brings less rainfall further north in Gedaref State (~15°N latitude), while it lasts longer and delivers more rainfall further south in Blue Nile State (~10°N latitude), though the season's duration varies interannually. The majority of annual rainfall – 80% in Blue Nile State, and 90% in Sennar and Gedaref states – occurs between June and September.

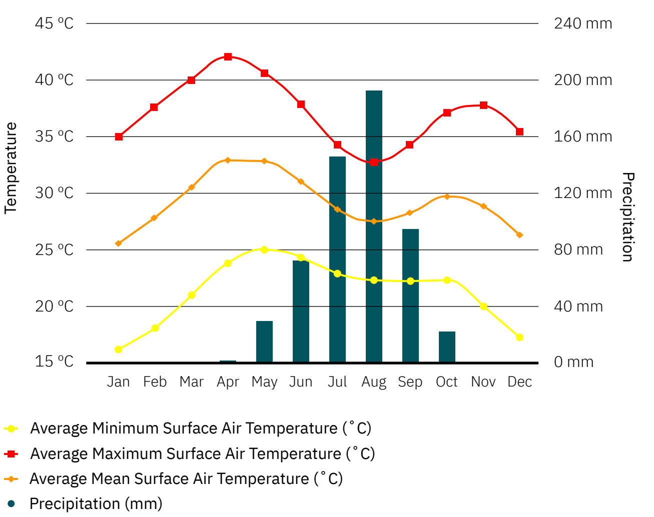
Precipitation in southeast Sudan varies widely from year to year, partly due to the effects of periodic changes in sea surface temperatures in the Indian Ocean and globally. In particular, El Niño and positive Indian Ocean Dipole phases tend to correlate with a delayed or weaker rainy season in southeast Sudan, resulting in drier conditions than average, while La Niña phases tend to correlate with more intense observed precipitation.[3] The inherent variability in El Niño-Southern Oscillation and Indian Ocean Dipole phases across years and decades, and their alternating potential to lead to both extreme floods and droughts, influence southeast Sudan's expected near, medium and long-term climate impacts.

Observed temperature and precipitation records over the last 50 years (1971–2020) reflect a significant warming and drying trend. During this period in Sennar State, mean annual temperatures significantly increased by 0.36°C per decade, while average maximum and minimum temperatures increased by 0.38°C per decade and 0.25°C per decade, respectively.[I] The greatest temperature increases occurred during autumn months in Blue Nile State, and hot and humid Heat Index days with maximum temperatures above 35°C significantly increased in

I Mean temperature in Blue Nile State significantly increased by 0.40°C per decade, while its maximum temperature increased by 0.47°C and minimum temperature increased by 0.26°C per decade. Mean temperature in Gedaref State significantly increased by 0.39°C per decade, while its maximum temperature increased by 0.42°C and minimum temperature increased by 0.31°C per decade.

Sennar State by 1.68 days per decade.[II] Observed annual precipitation over the last 50 years (see **Figure 1b**) significantly decreased by 59 mm per decade in Gedaref State, 73 mm per decade in Sennar State and 99 mm per decade in Blue Nile State throughout the rainy season. DNP's seasonal declines best match the average for Blue Nile State, with -37 mm per decade during summer months and -33 mm per decade during autumn months. Maximum consecutive dry days significantly increased by 5.38 days per decade in Blue Nile State, and only slightly less in Sennar and Gedaref states. Importantly, future projected climate scenarios do not necessarily suggest that these regional and seasonal trends will continue (as detailed below).

Monthly Climatology of Average Minimum Surface Air Temperature, Average Mean Surface Air Temperature, Average Maximum Surface Air Temperature & Precipitation 1991-2020; Sunnar, Sudan



Precipitation Trend per Decade (Annual), 1971-2020; Sudan

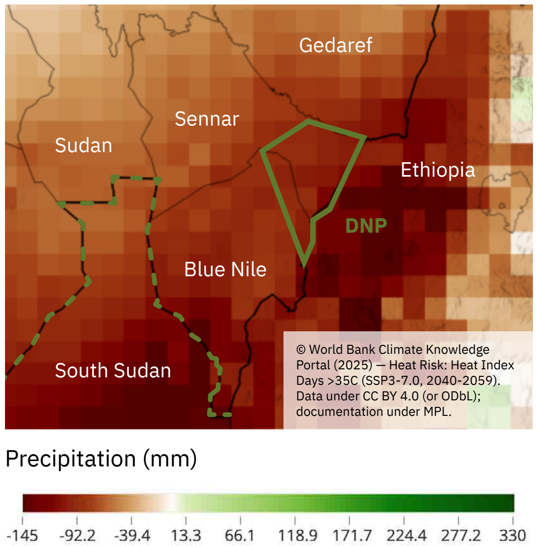


Figure 1.[III] **Left, a: Monthly Average Temperature and Precipitation (1991–2020) in Sennar State.** Note the warmest temperatures in April and May before the onset of the rainy season, and peak rainfall between June and September. **Right, b: Observed Annual Precipitation Trend per Decade (1971–2020) in Southeast Sudan.** Note the most significant decline in precipitation within the approximate bounds of DNP (grey boundary), Blue Nile State and the lowlands across Sudan's border with Ethiopia.

Projected Climate

The following projections explore future effects of a low-emissions SSP1-2.6 scenario and high-emissions SSP3-7.0 scenario, referencing additional climate scenarios when appropriate, across short term (2020-39), medium term (2040-59) and long term (2060-79) outlooks. Best estimates represent the middle percentile value (median) from a range of climate model projections, while the possible ranges shown in parentheses indicate the lower (10th percentile) and upper (90th percentile) bounds of these projections. It is important to note that these ranges show how much the different models agree with each other under each plausible what-if scenario, but these probabilities do not represent forecasts nor indicate the likelihood of a particular scenario occurring. As a result, uncertainty icons guide appropriate interpretation for decision-makers. For further details regarding climate scenarios, data sources, presentation and uncertainty, see adelphi's Supplemental Information.

II Blue Nile State also observed a significant increase of 6.35 tropical nights per decade with minimum temperatures above 20°C. Gedaref State observed an increase of 4.31 tropical nights per decade.

III Data and visuals for both figures produced using: World Bank (2025). Climate Change Knowledge Portal. From: https://climateknowledgeportal.worldbank.org/

HOW TO INTERPRET FUTURE CLIMATE SCENARIOS

A scenario describes a trajectory of future conditions based on a set of key assumptions. It is an important tool for both climate and social scientists to understand and plan for the effects of complex and unpredictable interactions between human and natural systems over various timeframes. The Intergovernmental Panel on Climate Change's *Sixth Assessment Report* draws on a handful of hypothetical future scenarios, known as Shared Socioeconomic Pathways (SSPs). These scenarios are simulated using a large number of computer models to explore potential future social and climate conditions. Each scenario is based on a range of socioeconomic (e.g., population, economic, technological and governance) assumptions and associated emissions trajectories.

The Climate Impact Profiles prioritise analysis of (1) the SSP3-7.0 scenario, as it explores the effects of high-adaptation challenges under a pessimistic warming scenario and regional conflicts, and (2) the SSP1-2.6 scenario, as it explores the effects of low-adaptation challenges under an optimistic warming scenario and greater international collaboration. Where possible, analysis notes deviations compared to other scenarios in the near and medium terms.

Uncertainty in projections is indicated with the symbol throughout the profile. Additional details are specified in the corresponding purple text. Refer to the How to Interpret Uncertainty in Climate Change Projections section in the Supplementary Methodology for more on the relationship between model scenarios and probability.[4]

Air Temperature

Southeast Sudan faces significant temperature increases under both high-emissions (SSP3-7.0) and low-emissions (SSP1-2.6) scenarios starting in the near term (2020–39), with greater scenario uncertainty affecting the magnitude – though not direction of temperature trends – over the medium term (2040–59) and long term (2060–79).[IV] Under the SSP3-7.0 scenario, annual mean temperature in Sennar State increases uniformly by a best estimate of 0.62°C (0.33°C and 1.01°C possible) over the near term, 1.46°C (0.85°C and 2.03°C possible) over the medium term and 2.29°C (1.42°C and 3.27°C possible) over the long term. The rate of warming under the low-emissions scenario surpasses that of the higher-emissions scenario over the near term, but the SSP3-7.0 scenario far exceeds the SSP1-2.6 projections over the medium and long term.[V] By mid-century under SSP3-7.0, the highest projected mean temperatures increase near the end of the dry season (March) and the lowest increases across the three states occur during the months of peak rainfall at the end of the rainy season (September–October). While annual mean temperatures in Blue Nile and Gedaref states remain relatively similar to Sennar State's by mid-century under both scenarios, Gedaref State's increase the most over the long term. For example, over the long term under SSP3-7.0, Gedaref State's mean temperature increases by a best estimate of 2.38°C (1.43°C and 3.33°C possible).

In Sennar State, the number of hot, humid days (Heat Index days with maximum temperatures > 35°C) **and warm tropical nights** (minimum temperatures > 26°C) **increase dramatically at similar rates before and after mid-century, though models disagree on the magnitude of increase** (see **Figure 2**). By mid-century under SSP3-7.0, the annual number of Heat Index days

IV In short, the SSP1-2.6 scenario refers to a future global trajectory of up to 2°C warming by 2100 that presumes low mitigation challenges and low adaptation challenges, realising net-zero CO_2 emissions after mid-century. The SSP3-7.0 scenario represents a future global trajectory with high mitigation and high adaptation challenges (including resurgent nationalism, regional conflict and insecurity), where by 2100 CO_2 emissions double and warming exceeds 3°C.

V Under SSP1-2.6, annual mean temperature increases by 0.80°C (0.30°C and 1.15°C possible) over the near term, but by 1.03°C (0.58°C and 1.71°C possible) over the medium term and 1.36°C (0.67 °C and 1.88 °C possible) over the long term. Under both scenarios, projected minimum temperatures increase at a slightly higher rate than annual mean temperature, while projected maximum temperatures increase at a slightly lower rate than annual mean temperature.

above 35°C dramatically increases by a best estimate of 67 days (39 days and 105 days possible) and under SSP1-2.6 by 45 days (22 days and 71 days possible). Over the long term, the annual number increases by a best estimate of 109 days (79 days and 164 days possible) under SSP3-7.0, compared with a median increase of roughly half that amount under SSP1-2.6. The greatest increases occur near the beginning (May and June) and end (October) of the rainy season.

At the same time, Sennar State's warm tropical nights, which prevent body temperature from adequately cooling down for restful sleep, increase by a best estimate of 72 nights (40 nights and 109 nights possible) over the medium term and 115 nights (74 nights and 175 nights possible) over the long term under SSP3-7.0, with similar shifts as Heat Index days across timeframes under SSP1-2.6. Tropical nights increase the most during spring and autumn months under SSP3-7.0 by mid-century, and all seasons except winter by 2080. High combined projected heat risks occur under all time periods and scenarios across Gedaref and Sennar states, especially in northern and western DNP. Such warm tropical nights raise heat-related mortality and morbidity rates, in combination with high daytime exposure, local environmental factors (e.g., loss of trees) and individual health risks (see Human Health section).[5]

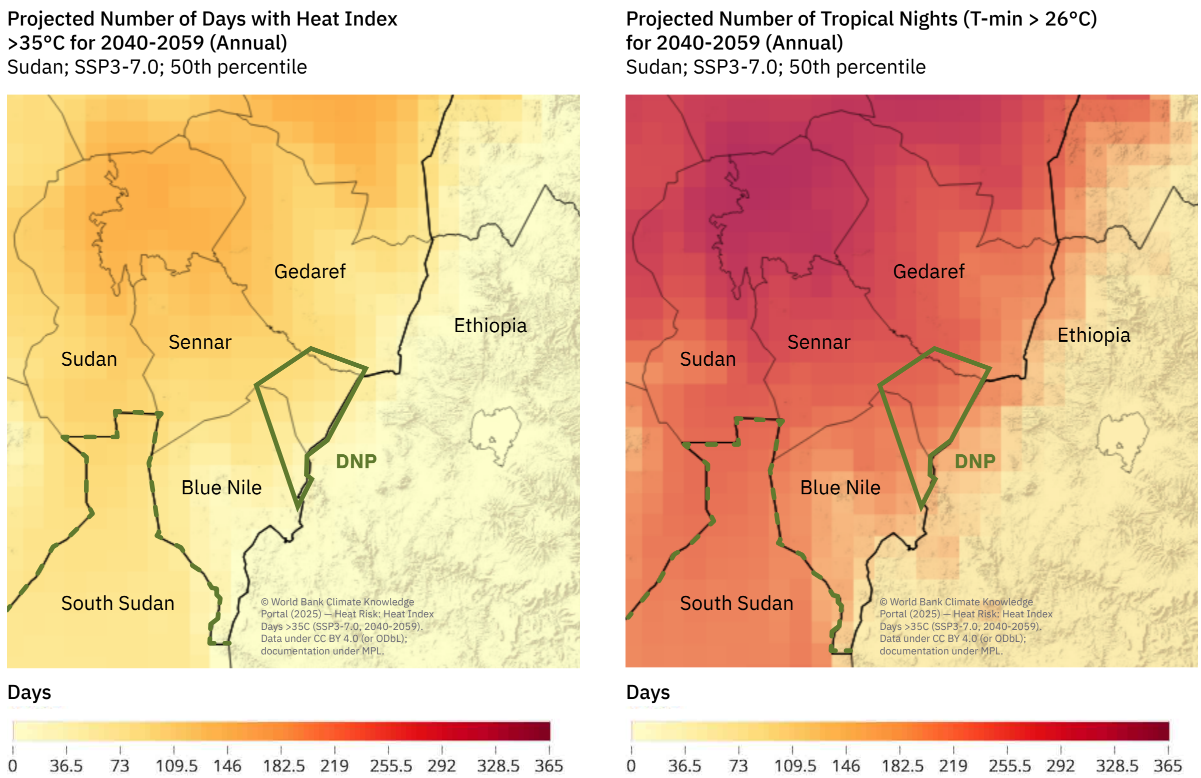


Figure 2.[VI] **Left, a: Projected Total Annual Number of Heat Index Days > 35°C by 2040–59 under SSP3-7.0.** Note more than two months of Heat Index days above the threshold temperature in northern Sennar State and western Gedaref State. **Right, b: Projected Total Annual Number of Tropical Nights > 26°C by 2040–59 under SSP3-7.0.** Note more than two months of tropical nights above the threshold temperature in northern and western DNP (green boundary).

VI Data and visuals for both figures produced using: World Bank (2025). Climate Change Knowledge Portal. From: https://climateknowledgeportal.worldbank.org/

Precipitation

Southeast Sudan's median projected precipitation totals increase annually over time, especially during the peak rainy season and late autumn months, but with high inherent interannual variability and mixed levels of model agreement over the near to medium term.[VII] Under the higher-emissions SSP3-7.0 scenario, mean annual precipitation in Sennar State increases by 29 mm (-51 mm and +102 mm possible) or 8% (-1% and +21% possible) over the near term, 53 mm (-51 mm and +131 mm possible) or 13% (+1% and +27% possible) over the medium term and 94 mm (-56 mm and +204 mm possible) or 15% (+3% or +41% possible) over the long term.[VIII] Under the lower-emissions SSP1-2.6 scenario, mean annual precipitation in the state increases by a larger median of 39 mm (-19 mm and +71 mm possible), with greater model agreement over the near term. Mean annual precipitation increases by a smaller but more directionally confident median of 42 mm (-21 mm and +100 mm possible), compared to the higher-emissions scenario over the medium term. Annual precipitation increases by a much smaller median increment of 33 mm (-13 mm and +95 mm possible) compared to the higher-emissions scenario over the long term, though models disagree on the magnitude of increase.

Meanwhile, the largest monthly change in precipitation occurs during the peak rainy season (September) over the near and medium term.[IX] The seasonal timing of the largest precipitation percentage change remains consistent in Sennar State over time under SSP3-7.0 and increases in model agreement, though potential magnitudes differ considerably (see **Figure 3a**).[X] Over the near term, Sennar State's largest monthly (November) increase of 24% (-17% and +95% possible) occurs over the near term, 33% (-12% and +131% possible) over the medium term and 53% (-8% and +197% possible) over the long term. This dramatic increase suggests a later shift in rainy season precipitation, of which Sennar State experienced many years during the 1950s and 1960s (see discussion below and **Figure 3b** for impacts on ecosystems and agriculture).

While annual and seasonal precipitation amounts under the two scenarios increase on average with more model agreement than not, **high and potentially increasing interannual variability (i.e., extreme wet and dry years) simultaneously entails more frequently recurring, intense dry periods.** This occurs for two main reasons. First, the projected increase in mean and extreme temperatures year-round magnify the rate of evapotranspiration, reducing the extent to which expected precipitation levels effectively moisten the soil, which in turn reduces runoff. Second, Sudan experiences inherent interannual variability correlated with El Niño-Southern Oscillation and Indian Ocean Dipole phenomena, both of which are projected to increase in intensity and variability, especially under higher-emissions scenarios (see Droughts section). For example, Sennar State's monthly projected percentage change in precipitation (**Figure 3a**) reveals a wide range of model uncertainty in April and May, the onset of the rainy season.

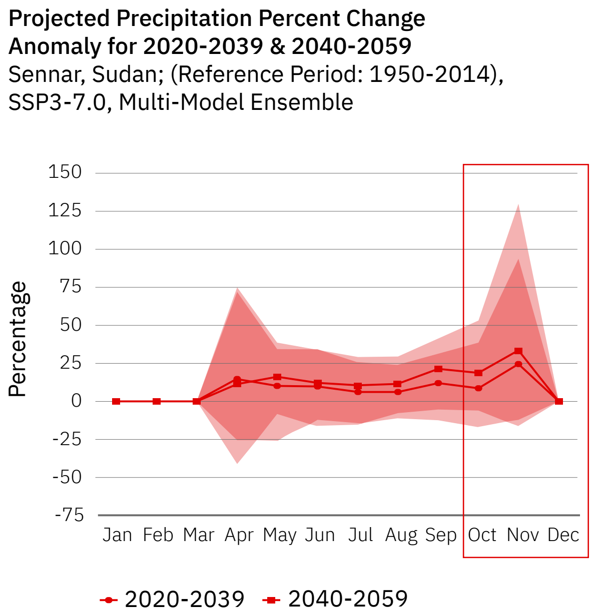
VII When discussing precipitation projections in this analysis, the statements "relatively high model agreement" and "more model agreement than not" indicate instances where either the lowest (10th percentile value) or highest (90th percentile value) model outcome of interest is at least two times larger than the other value, regardless of its sign. For example, a median projected precipitation increase of 5 mm with a range of model outcomes from -5 mm (10th percentile) to +15 mm (90th percentile) demonstrates relatively high model agreement, because the absolute value of +15 mm is much greater than -5 mm. This means that roughly one-third to one-half of all model outcomes could fall between +5 mm and +15 mm, and another one-third to one-half of all outcomes could fall between +5 mm and -5 mm, which raises confidence in the positive direction of future change, even though the exact magnitude of precipitation may be uncertain. By contrast, the statements "mixed model agreement," "lower model agreement" and "high model disagreement" indicate instances where the lowest and highest model outcomes of interest (10th and 90th percentiles) bear similar magnitudes but different signs, signifying more uncertain future change relative to the median.

VIII Mean annual precipitation trends do not differ significantly between the three states.

IX In Sennar State, precipitation in September over the medium term increases by 16.97 mm (-12.68 mm and +35.85 mm possible) under SSP3-7.0 and 12.47 mm (-6.35 mm and +24.90 mm possible) under SSP1-2.6. Similar seasonal trends and levels of uncertainty occur for the other two states.

X Median monthly precipitation percentage changes in Sennar State remain relatively similar under SSP1-2.6. Blue Nile State's monthly percentage changes generally increase by a lower amount and Gedaref State's monthly percentage changes generally increase a higher amount compared to Sennar State's.

This could indicate the delayed advance of rainy season precipitation during El Niño years and positive Indian Ocean Dipole phases. Projected changes in the 12-month Standard Precipitation Index, which indicate long-term drought conditions and display high levels of model disagreement, may likewise **suggest the alternation of very dry and very wet years over time**.



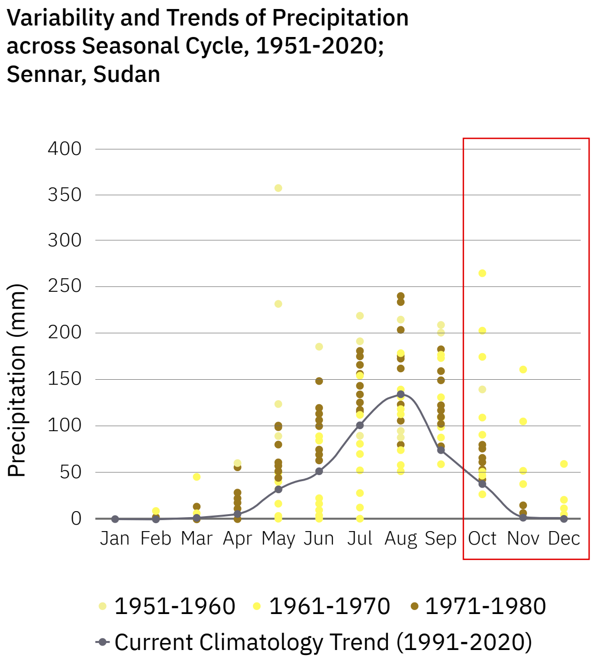


Figure 3. Left, a: Projected Precipitation Percentage Change in Sennar State for 2020–39 and 2040–59 (Ref. 1950-2014) under SSP3-7.0. Note largest median increases in November with large magnitudes possible and greatest model disagreement during the onset of the rainy season (April–May). Shaded areas indicate 10th and 90th percentile ranges. **Right, b: Monthly Historical Precipitation Variability (1951–80) in Sennar State Compared to Current Climatological Trendline (1991–2020).** Note the large precipitation variability during the late rainy season (October–December) in 1951–60 and 1961–70 (yellow dots), compared to the current climatological trend (grey line), which serves as a historical analogue to future projected seasonal precipitation timing and variability.

Precipitation intensity, measured by the average largest monthly precipitation amount during a one-day period, seasonally increases under both scenarios but displays uncertain timing across the three states (see Table 1). In the near term, precipitation events at this intensity increase the most in Gedaref and Sennar states under SSP3-7.0 during early rainy season months. Gedaref State's greatest monthly increase of 3.91 mm (-8.99 mm and +15.80 mm possible) in July maintains the strongest model agreement. By mid-century, events at this intensity during peak rainy season (September) increase the most in Sennar State under SSP3-7.0 by 4.92 mm with similar model agreement (-9.57 mm and +17.36 mm possible). However, across the same time period under SSP1-2.6, the largest increases with relatively less model agreement occur in Gedaref State, followed by Blue Nile State, in the late and typically receding rainy season. Average largest one-day precipitation totals increase most by 8.53 mm (-4.92 mm and +20.31 mm possible) during the peak rainy season of September in Sennar State over the long term under SSP3-7.0. This long-term trend maintains relatively strong model agreement with large upper magnitudes possible. Whereas under SSP1-2.6, the change in long-term precipitation intensity trends plateau, lack equivalent model agreement compared to SSP3-7.0, and deviate by state in their monthly timing. **Projected changes in precipitation intensity ultimately increase over time with greater model agreement under SSP3-7.0, but the seasonal timing in the near and medium term varies widely and underscores the need for decision-makers to prepare for more erratic seasonal, annual and interannual precipitation**. (See Floods and Droughts sections for further discussion on the implications of these patterns).

State	SSP1-2.6		
	Near Term	Medium Term	Long Term
Gedaref	July: **+3.40** (-8.95, +15.51)	Nov: **+3.65** (-8.61, +13.02)	Nov: +3.30 (-9.63, +13.48)
Sennar	Aug: +2.38 (-8.99, +10.75)	June: +2.05 (-6.22, +8.65)	June: +2.82 (-5.84, +9.63)
Blue Nile	June: +2.31 (-3.71, +9.83)	Nov: +2.44 (-4.99, +10.58)	Sept: **+3.72** (-5.11, +10.84)
State	**SSP3-7.0**		
	Near Term	Medium Term	Long Term
Gedaref	July: **+3.91** (-8.99, +15.80)	Sept: +3.29 (-10.14, +13.45)	July: +6.27 (-10.08, +19.49)
Sennar	June: **+3.91** (-10.95, +12.84)	Sept: **+4.92** (-9.57, +17.36)	Sept: **+8.53** (-4.92, +20.31)
Blue Nile	June: +3.79 (-7.45, +12.05)	Sept: +4.14 (-3.56, +17.92)	Sept: +7.91 (-4.03, +21.04)

Table 1. Greatest Median Monthly Change in Projected Average Largest One-Day Precipitation (mm) for Southeast Sudan across Near-Term (2020–39), Medium-Term (2040–59) and Long-Term (2060–79) Time Periods under High and Low-Emissions Scenarios (Ref. Period 1995–2014). Largest monthly median increases per time period bolded and outlined in red. Seasonal timing of largest monthly median increase shaded light teal (early rainy season), darkest teal (peak rainy season) and darker teal (late rainy season). Note greatest median increases occur under SSP3-7.0 over the long term, but seasonal timing and model agreement (10th percentile, 90th percentile) per state otherwise vary extensively.

Floods

Future climate scenarios project riverine flood risk in DNP to increase, but inherent climate variability remains high over the near and medium term, and watershed subbasins display different behaviour. Two major catchments encompass most of the park, the 750 km-long Dinder River and its nearly 35,000 km^2 basin and the 800 km-long Rahad River with a 42,500 km^2 basin.[6] Both rivers follow a similar path, flowing westward from the Ethiopian Highlands through the centre (the Dinder River) and along the northern boundary (the Rahad River) of DNP, then continue downstream through Sennar State before joining the Blue Nile River. The Dinder and Rahad rivers typically flow from July to December, peaking around August to September, receding during October and November, and drying up between January and June. Several major seasonal tributaries – including the Khor Kenana in western DNP and the Dinder River's largest tributary, the Khor Gelagu, in central DNP – flow during the rainy season and exhibit large variability from year to year, sustaining wetlands and pools of water for wildlife and livestock during the dry season (see Ecosystem Impacts section).

Recent records indicate the Rahad River's annual and seasonal (August–September) flows growing larger, and the Dinder River's low-flow volumes increasing in the autumn, both of which persist under future scenarios and time periods with mixed model agreement and many contributing drivers.[7] As discussed in the Projected Precipitation section, while median annual precipitation increases occur under future projections across southeast Sudan, this trend may disproportionately reflect increasing precipitation intensity during the peak months of the rainy season.[8] Localised downpours along the Rahad River, for example, can cause up to 80 cm of flash flooding.[9] Shifts in the intensity and timing of late-season precipitation, meanwhile, increase the potential exposure of people and animals, causing disruption to park operations during typically drier months. Other factors, such as land-use change and El Niño-Southern Oscillation phenomena (see Droughts section), also influence the amount of runoff that reaches the Dinder and Rahad rivers, with 30% of the combined watershed's area located in Ethiopia, not Sudan.[10]

Figure 4 illustrates the extent of inundation from a wetter possible model scenario with a relatively frequent (10-year) return period under a high-emissions trajectory (SSP3-8.5) over the near term. Compared to baseline conditions, inundation along segments of the Dinder and Rahad rivers through DNP increase, and manifest by mid-century under a lower-emissions SSP2-4.5 scenario, though with less model agreement. The middle section of the Dinder River through DNP possesses extremely high baseline riverine flood risk and high flood risk downstream of its confluence with the Khor Gelagu, which itself poses medium-high flood risk. By comparison, the SSP2-4.5 Middle-of-the-Road emissions scenario projects that inundation levels associated with 100-year flood events will increase along the Dinder River further upstream (Ethiopia) starting in the near term, with greater model agreement over time. Extremely high baseline flood risk characterises the Khor Kenana in western DNP and high flood risk characterises the course of the Rahad River (north) through DNP, which is capable of overflowing its banks and reaching a depth of 3 m.[11] Importantly, the Khor Abu Al-Hasan (medium-high baseline flood risk) conveys floodwater from the Rahad River to the Dinder River downstream of DNP boundaries under extreme events.[12] (See **Table 2** for a summary of flood risk exposure impacts).

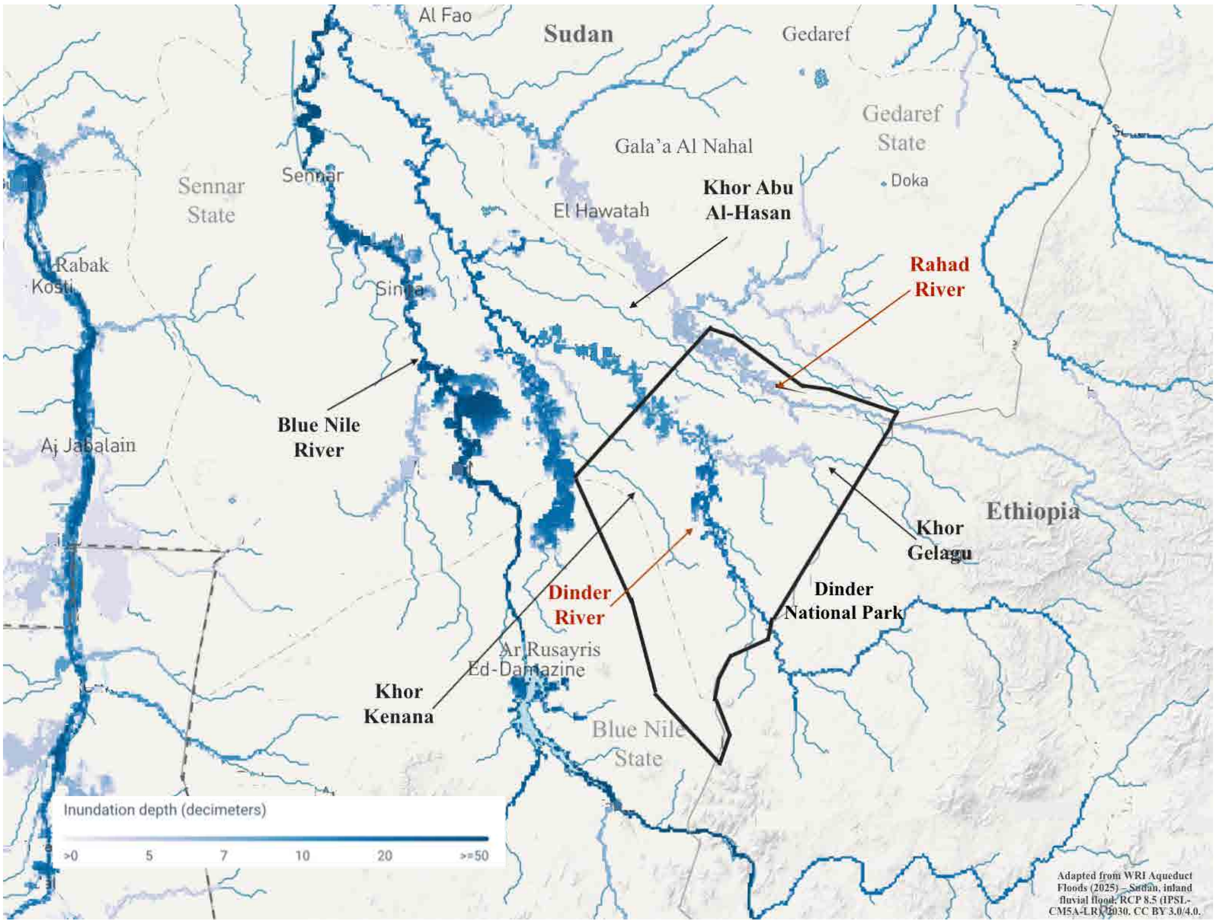


Figure 4. Projected Inundation Associated with 10-Year Riverine Floods in DNP over the Near Term (2030) under SSP5-8.5 (WRI Aqueduct 4.0 Flood Model IPSL-CM5A-LR).[13] Note inundation levels of the Dinder and Rahad rivers inside DNP boundaries (solid black line), downstream of the Khor Kenana outside park boundaries, and location of the Khor Abu Al-Hasan, which connects the Dinder and Rahad rivers under extreme flood conditions.

Droughts

As mentioned previously, **higher temperature-driven evaporation rates, coupled with more frequent and intense interannual precipitation variability, increase DNP's future drought risk, despite median projected precipitation increases.** Severe meteorological and agricultural droughts in Sudan caused food insecurity and human displacement throughout the 1970s, 1980s and 1990s.[14] Severe long-term droughts between 1961 and 2013, as measured by the 12-month Standard Precipitation Index, occurred with high frequency particularly in the vicinity of the Dinder and Rahad river basins.[15] Recent research points to a strong connection between the Nile River Basin's interannual and inter-decadal drought impacts, and cyclical sea surface temperature changes associated with positive Indian Ocean Dipole phases, as well as El Niño years.[16] Under the enhanced warming of future climate scenarios, drought impacts, and variability of El Niño-Southern Oscillation and Indian Ocean Dipole phases also increase, resulting in very dry periods alternating with more intense wet years.[17]

The current baseline risk of combined meteorological, agricultural and socioeconomic droughts remains moderate across DNP, except for medium-high risk along the Khor Kenana in western DNP and along the Dinder River downstream of its confluence with the Khor Gelagu in northern DNP (Sennar State).[XI] Water stress during the dry season remains particularly high across low and high-emissions scenarios along the Khor Kenana and Khor Abu Al-Hasan (north of DNP) starting in the near term. Seasonal water variability ranks at least medium-high throughout regional river basins across scenarios and timeframes by mid-century. However, due to the strong correlations between drought impacts in DNP, and El Niño-Southern Oscillation and Indian Ocean Dipole phases, interannual water supply variability acts as one of the most indicative metrics of future water shortages in DNP. Interannual variability in the Khor Kenana and Khor Abu Al-Hasan become extremely high starting in the near term under SSP1-2.6 and medium term under all scenarios. The Dinder and Rahad rivers face medium-high interannual water variability beginning in the near term under both emissions scenarios. For some river stretches, variability increases in the medium and long term, depending on the scenario (see **Table 2** for a summary of drought risk and impacts).

XI Based on WRI Aqueduct 4.0. See Kuzma, S., M.F.P. Bierkens, S. Lakshman, T. Luo, L. Saccoccia, E. H. Sutanudjaja, and R. Van Beek (2023). Aqueduct 4.0 Technical Note: Updated Decision-Relevant Global Water Risk Indicators. Washington, DC: World Resources Institute. DOI: https://doi.org/10.46830/writn.23.00061; adelphi (2025). Climate Impact Profiles Supplemental Information. Weathering Risk Programme. URL: https://weatheringrisk.org/en/publication/climate-impact-profile-supplementary-information

Sectoral Impacts

The following sections outline projected climate impacts by sector considering the temperature and precipitation indicators described above. Sector-specific metrics are further detailed in adelphi's Supplemental Information and interdisciplinary research findings.[XII] Livelihoods are particularly at risk. Livelihoods in the transitional zone of DNP and outside park borders differ widely across villages and households, where families maintain diverse ethnic origins (western Sudanese, West African, Arab and Nilotic) and frequently rely on income from more than one type of economic activity.[XIII] Agricultural activities, which as a sector make up an estimated 40% of the country's GDP, include cultivation of cash crops (e.g., sesame and groundnut) as well as subsistence cultivation of staple crops (e.g., sorghum, millet, fruits, vegetables and legumes) for local mainstays.[18] However, half of agricultural GDP comes from livestock-raising activities, and agriculture and livestock together employ 80% of people nationwide.[19] Additionally, collection of forest and non-forest timber products – including construction wood, fuelwood and charcoal, gum arabic, fruit and fodder, and handicraft and medicinal products – generate more than half of rural household income across Sudan, with gum arabic responsible for an estimated 17% of total Sudanese exports.[20] Future climate conditions amplify health, safety and economic risks across three important value chains: (1) livestock raising, (2) agriculture, and (3) the harvesting of forest and non-forest timber products (see discussion below and **Table 2** for impacts on each value chain).

Ecosystems

DNP's protected biodiversity faces habitat loss, degradation and fragmentation due to rising temperatures, as well as increasing resource competition linked to more frequent and intense precipitation variability. Located between the Sahel and Ethiopian Highlands, the park covers nearly 10,300 km^2, and includes **savanna-woodland, riverine and wetland ecosystems.** These habitats support 250 bird species, and dozens of large herbivore, fish and reptile species, most of which are concentrated in the core wildlife zone that makes up 53% of DNP's total area.[21] The core wildlife zone features more than 40 floodplain meadow wetlands (mayas), which populate oxbow lakes along the Dinder River and its tributaries, that act as refuges of water and vegetation for wildlife during the dry season.[22] While the core wildlife zone also hosts deciduous and evergreen species – most commonly *Acacia senegal*, *Acacia seyal*, *Balanites aegyptiaca* and *Combretum spp*. – the park permits local access to the buffer zone surrounding it (26% of DNP's total area) to engage in sustainable livelihood activities.[23] The outermost transition zone (21% of total area) extends 5 km from park boundaries, including across the northern bank of the Rahad River (Gedaref State) and the southern border with Blue Nile State, where most nearby villages are located and livestock herders visit. While the projected increase in maximum temperatures may affect the health of individual species, and contribute to habitat loss and fragmentation by causing higher rates of evapotranspiration, future precipitation and hydrological variability

XII For further details regarding climate scenarios, data sources and presentation see adelphi's Supplemental Information: https://weatheringrisk.org/en/publication/climateimpact-profile-supplementary-information

XIII Besides livestock-raising, farming and (non-)forest timber harvesting, other livelihood activities in the DNP area facing similar climate-related implications – though not elaborated in greater detail – include informal trading, day-labouring, hunting and fishing. See Geleto, M.A., Kapp, G. and Sanjak, E. (2023). Coping with Local Peoples' Livelihood Dependence on the Transboundary Dinder–Alatish National Parks in Sudan and Ethiopia from the Sudanese Perspective. Environment, Development and Sustainability, 25(4): 3099-3121. DOI: https://doi.org/10.1007/s10668-022-02170-4; UNEP (2020). Sudan First State of Environment and Outlook Report. UNEP. URL: https://www.unep.org/resources/report/sudan-first-state-environment-outlook-report-2020; El Hussien, R.A.Y, Ahmed, F.A.M., and R.R.M. Salih (2012). Evaluation of the Impact of Dinder National Park Project (DNPP) on the Local Community in Dinder Area, Sudan. J. Life Sci Biomed.2(3):101-104. DOI: https://www.researchgate.net/profile/Reem-Mohammed-6/publication/272679919_Evaluation_of_The_Impact_of_Dinder_National_Park_Project_DNPP_on_the_Local_community_in_Dinder_Area_Sudan/links/54eb66520cf2082851bdc63f/Evaluation-of-The-Impact-of-Dinder-National-Park-Project-DNPP-on-the-Local-community-in-Dinder-Area-Sudan.pdf act as key limiting factors.[XIV] Flora and fauna populations stand to benefit from greater annual precipitation on average, especially since individual species can migrate to relatively drier or wetter climate gradients while still inside DNP.[XV] However, more frequent and intense floods and droughts threaten to degrade DNP's ecosystem services. Water shortages and surpluses affect the quality of biomass for food and habitat, which by extension affect functional capacities for air and water purification, flood management, nutrient cycling, and carbon sequestration (see discussion below).[24] Such ecological functions provide additional services for local communities in the form of human resources (e.g., raw materials for construction, fuel and medicinal purposes), economic benefits (e.g., park jobs, ecotourism and sustainable livelihoods) and intangible cultural (e.g., aesthetic, folkloric and educational) benefits (see livelihood-related value chains sections).

Shifts in precipitation timing, magnitude and variability affect habitat quality and species abundance, since they depend on the extent to which available water supplies last throughout the dry season.[25] Relatively strong model agreement on wetter conditions during peak rainy season months (June–September) and a shift to wetter conditions late-season (October–November) suggest more intense high-flow, and more frequent and intense low-flow events, respectively. Mayas moderate floods by absorbing excess runoff but their capacities diminish under extreme conditions and severe erosion. Similarly, frequent cycles of drought followed by flooding lead to sedimentation of wetlands and degradation by tall seasonal grasses.[26] Increasing interannual and seasonal variability particularly affects the Dinder River's main seasonal tributary, the Khor Gelagu in the core wildlife zone (Sennar State).

Future climate impacts further exacerbate the adverse effects of human activities on biodiversity in DNP, such as erosion and habitat degradation stemming from deforestation, land-use change, overharvesting and overgrazing. Land cover in DNP, and the Dinder and Rahad watersheds across the Ethiopian border have transformed significantly since the 1970s, with waves of famine-fuelled migration leading to the replacement of woodlands with grasslands and shrubland. More recently, unplanned mechanised agriculture surrounding and upstream of DNP, despite reforestation efforts, contributed to increased runoff along the Rahad River in the transition zone (Gedaref State), in addition to disrupting animal migration patterns, reducing rangeland for grazing and in effect lowering species abundance over time.[27] This could increasingly affect the Dinder River watershed in the future, as illegal felling and overharvesting of trees such as *A. aegyptiaca* remove soil fertility in the buffer zone, transition zone and outside park boundaries (Sennar State).[28] Significantly, greater precipitation between October and December may further encourage the loss of soil nutrients from grassland fires associated with cooking, honey collection, charcoal production and agriculture.[29] Areas south of the Khor Gelagu in the core wildlife zone (Sennar State), and west of the Dinder River in the core wildlife and buffer zones (Sennar State) experienced the highest frequency of fires during the 2010s.[30] Considering future shifts in late-season rains, and the potential for more extreme wet and dry years, **decision-makers should re-evaluate DNP's critical biodiversity and natural resource management practices** (e.g., sustainable land use, resource harvesting, fire-setting and migratory routes), **and their designated spatial and temporal terms of use or access**, particularly in the park's buffer and transitional zones during the traditional dry season.

XIV For example, maximum of daily maximum temperatures during the hot spring months under SSP3-7.0 increase in Sennar State by 1.93°C (0.94°C and 2.59°C possible) over the medium term. See Hassaballah, K.E.A. (2021). Land Degradation in the Dinder and Rahad Basins: Interactions between Hydrology, Morphology and Ecohydrology in the Dinder National Park, Sudan. CRC Press. URL: https://research.tudelft.nl/en/publications/land-degradation-in-the-dinder-and-rahad-basins-interactions-betw; Basheer, A.K., Lu, H., Omer, A., Ali, A.B. and Abdelgader, A.M. (2016). Impacts of Climate Change under CMIP5 RCP Scenarios on the Streamflow in the Dinder River and Ecosystem Habitats in Dinder National Park, Sudan. Hydrology and Earth System Sciences, 20(4): 1331-1353. DOI:10.5194/hess-20-1331-2016

XV Ibid.

Human Health

Over the short and medium term, climate-related health risks, including heat stress, vector-borne diseases and water-borne diseases, are generally projected to worsen. Combined heat risk, comprised of hot and humid daytime temperatures (Heat Index Days above 35°C) **and warm nighttime minimums** (Tropical Nights above 26°C) that prevent body temperature from adequately cooling down, **increase most at the beginning and end of the rainy season**. Models show relatively high agreement under SSP3-7.0, starting in the near term (see **Figure 2**). While the severity of future heat stress depends on localised and individual risk factors, Heat Index days between 32°C and 41°C can trigger heat cramps, heat exhaustion, dehydration and heat stroke with prolonged exposure or physical activity.[31] **Heat-related mortality** significantly increases above 31ºC and **disproportionately affects outdoor labourers in more densely settled irrigated areas along the Rahad River** in the transitional zone (Gedaref State), **and downstream of the Dinder and Blue Nile rivers outside DNP** (Sennar State) (see Table 2).[XVI] For reference, projections for Sudan indicate that heat risk exceeds safe working conditions for more than 10% of annual hours by mid-century under a Middle-of-the-Road SSP2-4.5 scenario, particularly where access to electricity and basic water infrastructure remains limited.[XVII] Heat stress risks also disproportionately affect elderly people, children, pregnant women and people with chronic diseases.

Projected temperature increases, combined with extreme precipitation variability, are expected to shift the timing, intensity and geographic distribution of vector-borne diseases (e.g., malaria) and water-borne disease (e.g., diarrhoeal disease) in southeast Sudan over the near and medium term. Across Sudan, reported malaria incidence rose significantly over the last ten years, reaching an estimated 5 million cases nationwide in 2024.[32] Pregnant women and children under 5 years of age face disproportionate risks. Endemic malaria transmission by parasite-carrying mosquitoes typically occurs year-round, but peaks at an optimum temperature of 25°C and towards the end of the rainy season, when suitable breeding sites increase, including standing water and water stored in containers.[33] Because transmission can decline at higher temperatures, projected increases in Heat Index days above 35°C and tropical nights above 26°C suggest that southeast Sudan could see *lower* incidence and reduced malaria transmission by mid-century. However, observations in Gedaref and Sennar states since 2019 indicate the reported emergence of more heat-tolerant mosquitoes from Asia that are capable of spreading malaria and other vector-borne diseases.[34] This underscores the need for further study of malaria risks in southeast Sudan, especially considering more extreme flood episodes and changes in type and timing of riverine flooding, including high-flow and low-flow events.

By contrast, the region already faces increasing risks of other vector-borne diseases. Medical professionals continue to report outbreaks that occur at warmer optimum temperatures and following heavy rainfall events.[XVIII] Southeast Sudan acts as a major corridor for human

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XVI Elevated rates of heat risk occur most of the year across scenarios and timeframes. See Richardson, K., Calow, R., Pichon, F., New, S. and Osborne, R. (2022) Climate Risk Report for the East Africa Region. Met Office, ODI, FCDO. URL: https://reliefweb.int/report/ethiopia/climate-risk-report-east-africa-region

XVII Defined here as average annual maximum global wet bulb temperature above 26.5ºC, which unlike Heat Index conditions, captures outdoor exposure to direct sunlight. See Masuda, Y.J., Parsons, L.A., Spector, J.T., Battisti, D.S., Castro, B., Erbaugh, J.T., Game, E.T., Garg, T., Kalmus, P., Kroeger, T. and Mishra, V. (2024). Impacts of Warming on Outdoor Worker Well-Being in the Tropics and Adaptation Options. One Earth, 7(3): 382-400. DOI: https://doi.org/10.1016/j.oneear.2024.02.001

XVIII These include: Rift Valley Fever, yellow fever, dengue, chikungunya, and leishmaniasis, among others. Many of these diseases display symptoms (e.g., fever) mistaken for malaria. Historical prevalence of Rift Valley Fever is greatest in Sennar State, yellow fever is greatest in Sennar and Blue Nile states, dengue is greatest in Gedaref State, and chikungunya and leishmaniasis are greatest in Gedaref and Sennar states. See Mordecai, E.A., S.J. Ryan, J.M. Caldwell, M.M. Shah, and A.D. LaBeaud (2020). Climate Change Could Shift Disease Burden from Malaria to Arboviruses in Africa. The Lancet Planetary Health 4(9): e416-e423. DOI: https://doi.org/10.1016/S2542-5196(20)30178-9; Ahmed, A., L. Dietrich, A.D. LaBeaud, S.W. Lindsay, A. Musa, and S.C. Weaver (2020). Risks and Challenges of Arboviral Diseases in Sudan: The Urgent Need for Actions. Viruses 12(1): 81. DOI: https://doi.org/10.3390/v12010081;

and animal migration, which also heightens the risk of vector-borne diseases such as Rift Valley Fever. The virus can spread from infected livestock to humans through direct contact or consumption of raw animal products, with knock-on effects for livestock-dependent economies and local food security.[35] Certain livelihood activities further raise infection risk. In and around DNP, parasite-carrying sandflies, which feed on prevalent gum arabic trees, transmit leishmaniasis. Rural farming and forestry workers face particularly high risks, in addition to children.[36] **Conflicts can further increase vector-borne and water-borne disease risks, particularly where basic services and health care infrastructure deteriorate and displacement is widespread**. For example, a 2019 outbreak of chikungunya in Gedaref State and dengue in Gedaref and Sennar states coincided with the overthrow of President Al-Bashir's regime, which led to mass displacement and worsening access to health care.[37]

Water-borne diarrhoeal diseases, including cholera, pose increasing risks in southeast Sudan. Projections indicate larger seasonal peaks in extreme precipitation (i.e., late rainy season) and warmer temperatures that support bacteria growth.[38] Cholera incidence often increases after floods, which can contaminate water sources, and during drought events, which can concentrate pollutants and increase reliance on unsafe water sources.[39] Outbreaks also occur in displacement camps due to overcrowding, food insecurity, unsafe hygiene practices and inadequate access to basic services and health care.[40] For example, floods in 2019 destroyed water, sanitation and hygiene (WASH) facilities and contaminated water sources for IDPs and nomadic groups in Sennar and Blue Nile states.[41] Since 2023, Gedaref State, which hosts a large number of IDPs (see Human Displacement), has been a hotspot for ongoing outbreaks due to untreated water. More than 56,000 people have been affected, which has led to over 1,300 casualties nationwide as of early 2025.[42]

Livestock-Related Value Chains

Extreme heat, flood and drought risks by mid-century adversely affect livestock animals in the DNP area, which primarily comprise cattle, sheep and goat raised for their milk and meat. However, the risks to individual livestock herders may **vary greatly, depending on** whether they practice **seasonal migration** (nomadic or semi-nomadic transhumance) or remain relatively sedentary (agropastoralism). Heat stress particularly affects cattle, and lowers the reproduction rates of sheep and goats, in addition to reducing the productivity of pastureland and raising water needs.[43] Combined heat risk for livestock from Heat Index days above 35°C and tropical nights above 26°C increases most across timescales and scenarios in Gedaref and Sennar states, both of which supported a livestock population of more than four million in 2017.[44] Flood and drought events may further result in significant livestock mortality, especially to sedentary herds (see Agriculture-Related Value Chains section). However, since (semi-)nomadic herders typically adapt to such conditions by migrating herds to less affected regions, the major impacts of extreme precipitation variability on such pastoralists involve resource conflicts with wildlife, and other land and water users along migration corridors, as well as increased susceptibility to pests and diseases.[45] For example, temperature increases coupled with extreme precipitation variability raise the risk of Rift Valley Fever, which resulted in livestock outbreaks in 2007 and 2019 that disrupted supply chains.[46] Overall, as shown in Table 2, **combined heat, flood and drought risks disproportionately affect Sennar State's livestock** (greater proportion of cattle), **followed by Gedaref State** (greater proportion of sheep and goats).[XIX]

XIX Though Blue Nile State possesses the largest population of cattle, sheep and goats (more than six million in total), it featured the smallest increases in assessed climate impact risks relative to the other states. This analysis primarily considered flood and drought impacts in the Dinder and Rahad river watersheds. Therefore, watershed impacts along the main artery of the Blue Nile River in Blue Nile State (outside DNP's transitional zone) would require further study of upstream dam construction and expanded downstream water usage from the Ar Rusayris reservoir. See Higher Council for Environment and Natural Resources (2022). Sudan's Third National Communication under the UNFCCC. Republic of Sudan. URL: https://unfccc.int/documents/646439; Gilbert, M., Cinardi, G., Da Re, D., Wint, W.G.R., Wisser, D., Robinson, and Timothy, P. (2022). Global Sheep Distribution in 2015 (5 minutes of arc), DOI: https://doi.org/10.7910/DVN/VZOYHM, Global Goats Distribution in 2015 (5 minutes of arc), DOI: https://doi.org/10.7910/DVN/YYG6ET, Global Cattle Distribution in 2015 (5 minutes of arc), https://doi.org/10.7910/DVN/LHBICE, Harvard Dataverse, V1; URL: https://dataverse.harvard.edu/dataverse/glw_4

Agriculture-Related Value Chains

By mid-century, extreme heat, flood and drought risks are projected to impact crop production, labour, distribution and trade differently across southeast Sudan (see Table 2). **Future impacts on agriculture production depend not only on annual mean temperature and precipitation increases, but also high interannual precipitation variability**.[47] The increase in minimum and maximum temperatures reduces the duration of the growing season's (June–October) optimum conditions for crops such as sorghum and sesame.[XX] Considering upper optimal temperature thresholds of 27ºC for sorghum and sesame, and 30ºC for millet,[48] the states of southeast Sudan exceed these conditions during their growing seasons under both scenarios by mid-century. When considering changes in mean precipitation, an increase in rainy season length boosts potential yields of sorghum in addition to other crops, though sorghum requires more water and thus remains more sensitive to water shortages than millet.[XXI] Under only temperature and precipitation conditions associated with a high-emissions (SSP5-8.5) scenario in central and eastern Sudan, Choi and Eltahir project approximately 10% yield losses for sorghum and millet, and 20% yield losses for sesame by mid-century.[49] On top of these factors, **localised riverine and flash floods increasingly result in major sudden crop losses, and damage to settlements and critical infrastructure.** In August 2022, heavy rain and flooding along the Rahad River (Gedaref State, outside DNP) affected more than 45,000 people, disproportionately impacting farmers with irrigated commercial gardens.[50] By contrast, **droughts tend to reduce longer-term productivity and result in even more widespread impacts**. Between 1970 and 2020, droughts affected more than 27 million people in Sudan and drought-fuelled famine killed an estimated 55,000 in 1984 alone, many in Gedaref State where a majority of residents still lack access to safe drinking water.[51]

Projections by Siddig et al. (see Table 2) combine these factors under a drier high-emissions scenario, which results in differing rates of decline in staple and cash crop yields by mid-century.[52] However, **yields** of staple crops (i.e., sorghum and millet) and cash crops (i.e., sesame and groundnuts) **differ according to whether the majority of production draws on irrigation or rainfed sources.** Rainfed sorghum yields, sensitive to water shortages and excesses, experience significant declines in Gedaref State. However, irrigated sorghum in Sennar State performs better, especially after introducing adaptive policy and technology measures. Like sorghum, most groundnut production located in Sennar State performs better under irrigated conditions. By contrast, rainfed millet declines in Gedaref and Sennar states, though not as much as rainfed sorghum. Rainfed sesame production declines in Gedaref and Blue Nile states at a similar rate as millet under a drier (lower-emissions) scenario, but does not benefit as much as millet does from a wetter (higher-emissions) scenario, which partly explains sesame's higher risk scoring. This preliminary risk analysis concludes that **groundnut and irrigated sorghum cultivation in Sennar State possess relative advantages.** However, other important factors such as land use, economic conditions, civil conflict and resource-sharing conflicts also affect future projections.[53] Despite the potential for higher staple crop yields, **mechanised farming schemes are more vulnerable to flood and drought** losses than traditional farming methods. This is because mechanised practices often involve tree clearing, monoculture cropping without rotation, and ploughing that compacts soils and depletes soil nutrients.[54]

XX A minimum temperature increase of 1ºC reduces sorghum yields by 260 kg/ha and maximum temperature increase of 1ºC reduces yields by 17 kg/feddan. See Osman, M. A. A., Onono, J. O., Olaka, L. A., Elhag, M. M. and Abdel-Rahman, E. M. (2021). Climate Variability and Change Affect Crops Yield under Rainfed Conditions: A Case Study in Gedaref State, Sudan. Agronomy, 11(9), 1680. DOI: https://doi.org/10.3390/agronomy11091680; Khalifa, E.A. (2016). Volatility of Sorghum Production under Rainfall System in Gadarif State, Sudan. Russian Journal of Agricultural and Socio-Economic Sciences, 56(8): 137-144. DOI: http://dx.doi.org/10.18551/rjoas.2016-08.17

XXI For example, an average precipitation increase of 1 mm raises sorghum yields by .11kg/ha. See Osman, M. A. A., Onono, J. O., Olaka, L. A., Elhag, M. M. and Abdel-Rahman, E. M. (2021). Climate Variability and Change Affect Crops Yield under Rainfed Conditions: A Case Study in Gedaref State, Sudan. Agronomy, 11(9), 1680. DOI: https://doi.org/10.3390/agronomy11091680; Choi, Y.-W. and Eltahir, E.A.B. (2023). Near-Term Climate Change Impacts on Food Crops Productivity in East Africa. Theoretical and Applied Climatology 152:843–860. DOI: https://doi.org/10.1007/s00704-023-04408-1

Future climate impacts also affect other aspects of crop value chains, including labour (see Human Health), distribution and trade. **Furthermore, extreme heat risks affect the harvesting of sesame and groundnut cash crops,** as they require more intensive labour.[55] After harvesting, most crops (e.g., sesame and groundnut) are stored at the household level before being further processed at the village level and then transported to larger town markets for domestic and cross-border trade.[56] The potential for **climate impacts** to disrupt the latter step in the value chain – transit to market – **poses greater risks for crops located either further away from their market destinations or along routes with higher flood risk.** Sites for both groundnut cultivation in Sennar State, and sesame cultivation in Gedaref and Blue Nile states maintain relatively close proximity to their town markets or transit hubs (Sinja vicinity, El Hawatah and Gedaref city, and Ar Rusayris and Ed Damazine, respectively).[XXII] Conversely, market access for individual smallholders growing sorghum and millet varies depending on the location. Gedaref State alone produces half of Sudan's value chains of sorghum and millet, and supports more people who mostly live in rural areas (more than two million in Gedaref State, compared to two million in Sennar State and one million in Blue Nile State as of 2022).[57] Therefore, sorghum and millet grown in Sennar State bound for wholesale markets in Gedaref State face greater risk of flood hazard exposure in transit compared to grain grown and sold in Gedaref State.[58] This was illustrated by the August 2022 floods along the Rahad River, which inundated pastureland and unpaved roads, isolated villages, restricted access to nearby towns and markets in Gedaref State, and heavily disrupted entire chains of food production, labour and trade.[59] **Distribution and trade networks in Sennar State face the greatest risk of flood-related disruption, followed by Gedaref State. However, risks vary at the farm level depending on the location of individual smallholders.**

Forest and Non-Forest Timber Product Value Chains

Based on preliminary evidence, **future climate impacts on non-forest timber product production, harvesting and trade may not matter as much as continued practices of overgrazing, overharvesting and illegal felling, the effects of which are further exacerbated by climate extremes**. For instance, increased future temperature and precipitation projections do not significantly increase the risks of gum arabic production from *A. senegal*, though losses may occur during extreme wet and dry years.[60] While degradation from overharvesting, overgrazing and illegal felling affected the abundance and yields of *A. senegal* in DNP, the *A. seyal* variety of gum arabic exhibited greater abundance and survival under such conditions, though this variety typically garners less revenue than the gum of *A. senegal* trees.[61] The expected net revenue generated across gum arabic species would, therefore, require further investigation. One study, as the best available proxy for non-forest timber product harvests excluding gum arabic across DNP's transition zone, reported the lowest yields of *B. aegyptiaca* (among the most commonly desired species for food, medicine and fodder in the park during the surveyed period 2020–21) in Blue Nile State villages followed by Sennar State.[62] Since overgrazing by goats produced the most degradation to species surveyed compared to other livestock, **non-forest timber product harvests at greatest risk of additional climate stress** (see Table 2) **occur in Blue Nile State, followed by Sennar State**.[63]

Other stages of non-forest timber product value chains deliver **variegated benefits to individual households, given unequal market access among other factors**. As previously discussed, extreme heat and precipitation variability pose the greatest risks to harvesters of non-forest timber products in Sennar State, followed by Gedaref State. However, climate impacts affect populations unevenly. Lower-income groups, and women engaged in activities such as fuelwood collection and fetching water face disproportionate impacts from droughts on top of the effects of environmental degradation and civil conflict. For example, though the lowest-income natural

XXII Based on spatial data for crop production from WRI's Aqueduct Food Model, and road networks with the best available detail according to UNHCR and Medecins sans Frontieres. See methodology for Food and Agriculture section in: adelphi (2025). Climate Impact Profiles Supplemental Information. Weathering Risk Programme. URL: https://weatheringrisk.org/en/publication/climate-impact-profile-supplementary-information; MSF (2023). Gedaref State General Reference Map. ReliefWeb. URL: https://reliefweb.int/map/sudan/sudan-gedaref-state-general-reference-map-10052023; UNHCR (2021). Blue Nile State UNHCR Presence and Refugee Locations. UNHCR. URL: https://data.unhcr.org/es/documents/details/84723 resource harvesters may not cause the most degradation, they may face greater consequences due to their resource dependence and the relative proportion of their budget spent on basic needs.[64] Distribution routes and trade centres for non-forest timber product value chains – primarily town markets – additionally face the greatest flood risk in Sennar State (Dinder town market nearest to DNP), followed by Gedaref State (El Hawatah town market). Within the limitations and scope of this analysis, **existing market access in Blue Nile State and areas of Gedaref State appears to offer relative advantages**.

Human Displacement

Climate-related impacts threaten to exacerbate already high levels of conflict-driven internal displacement, which rose sharply in southeast Sudan from 2023 onwards (see Focus Box on Sudan's wider armed conflict). **By the end of 2024, conflict-driven internal displacement affected 11.6 million nationwide, the highest figure globally.**[XXIII] **The effects of displacement disproportionately impact children and women. Many face high rates of food insecurity and sexual and gender-based violence. They also carry increased care responsibilities** when men leave for combat, while livelihood and employment opportunities remain limited.[65] In the Blue Nile State, for example, many IDPs rely on host communities and humanitarian organisations for food, since looting, labour shortages, intentional destruction of crops and natural resources and limited access to farming and grazing reduce viable opportunities in conflict-affected areas. At the same time, overstretched urban areas such as Ed Damazine face difficulties accommodating large inflows. IDPs face inflated food prices, competition over basic services and poor public health conditions. RSF-allied troop activities, which account for the majority of recorded violent incidents targeting civilians, also directly threaten displacement camps with armed conflict.[66]

Disaster-driven displacement interacts with conflict dynamics and exacerbates food and water scarcity, livelihood insecurity and competition over natural resources. Rapid-onset flooding in Sudan triggered 2.2 million internal displacements between 2008 and 2024.[67] In mid-2020, heavy rainfall contributed to the collapse of the Bout Dam in Blue Nile State, displacing approximately 100,000 people.[68] Such events are likely to increase as extreme precipitation becomes more frequent and severe. In Sennar State, the average annual displacement rate linked to flooding already exceeds one percent of the population, or an estimated 21,000 people.[69] Conflict can further constrain mobility and force people into riskier routes, for example, when the RSF diverted travellers to more hazard-prone access routes such as Dinder road.[70] Slow-onset droughts and precipitation variability also drive involuntary migration through food insecurity, natural resource competition and the loss of farming, pastoralist and forestry-based livelihood activities (risks summarised in Table 2).[71] Reduced crop yields can incentivize the expansion of irrigated and mechanised agriculture, displacement of rainfed subsistence farming and intensification of competition with pastoralists over grazing land.[XXIV] As a result, areas near converted or abandoned agricultural land, particularly those along migratory corridors, may become conflict hotspots in the vicinity of DNP. Between 1990 and 2017, the largest conversion from rangeland to agriculture occurred in Gedaref State, while the greatest encroachment on livestock routes occurred in Blue Nile State.[72]

XXIII This includes over one million IDPs in the state of Gedaref, between 250,000 and 500,000 IDPs in Blue Nile State, and no more than 250,000 in Sennar State. These figures do not include persons displaced outside of Sudan's borders, observed particularly in Ethiopia and South Sudan. See IDMC (2025). "Sudan – The World's Largest Internal Displacement Crisis Deepens." Internal Displacement Monitoring Centre. 13 May. 2025. URL: https://www.internal-displacement.org/spotlights/sudan-the-world-s-largest-internal-displacement-crisis-deepens/

XXIV Expansion of mechanised agriculture, dam construction and other development projects displaced nearly one million people in Sudan during the 2010s. See also Ecosystems section for more details on the relationship between displacement drivers and land use change. See Mohamed, E.S.E. (2020). Environmental Change, Conflicts and Internal Displacement as Destabilizing Factors to Food Security in Sudan: Econometric Analysis. Journal of Internal Displacement 10(1): 2-24. URL: https://www.ajol.info/index.php/jid/article/view/265202; Sulieman, H.M. (2024). Causes and Impacts of Farmer-Herder Conflicts through a Political Economy and Food Production Lens: Case Study in Gadarif State, Sudan. CGIAR. URL: https://cgspace.cgiar.org/items/94528443-938d-4c03-90cb-8d832734c2cb

Focus Box: At the Crossroads of Sudan's Wider Conflict

DNP's strategic location has repeatedly shaped its role in Sudan's armed conflict. The park lies along key corridors connecting the country's south and east with the capital and spans Blue Nile State, where the relationship with the central government has long remained contested.[73] This dispute partly stems from the 2005 Comprehensive Peace Agreement, which ended Sudan's 22-year civil war between the Sudanese Armed Forces (SAF) and the Sudan People's Liberation Movement/Army (SPLM/A) and designated Blue Nile State as an autonomous region. Following South Sudan's independence in 2011, the reconstituted Sudan People's Liberation Movement – North (SPLM-N) continued to pursue a secular, autonomous status for Blue Nile State, but split into two factions in 2017. The faction led by Malik Agar aligned with SAF and signed the 2020 Juba Peace Agreement, which reaffirmed commitments to support Blue Nile State's autonomous status.[74] The faction led by Abdelaziz Al-Hilu declined to sign the agreement and, following the country's 2021 military coup, supported the opposing paramilitary Rapid Support Forces (RSF). As tensions between SAF and RSF escalated, communities across Sudan rallied behind groups in support of one side or another. SAF armed a small occupying militia within DNP to act as the main security provider, drawing support from indigenous groups and from recent migrants seeking work on state agricultural projects.[75] RSF, in turn, drew support from the region's marginalised Arab groups and from nomadic pastoralists.

Rival SAF and RSF militias drove mass displacement in Sennar State as they fought for control of critical food and supply routes. They also continued to compete for territory, resources and alliances with influential groups.[76] At the end of 2023, RSF captured Wad Medani, the capital of Aj Jazirah State in central Sudan, prompting approximately half a million IDPs to flee south to Sennar State.[XXV] After RSF gained control of the strategic town of Dinder and the Sennar State capital, Sinja, by mid-2024, approximately 730,000 IDPs then left Sennar State for neighbouring regions.[77] SAF defended the city of Sennar throughout the conflict and later recaptured Dinder in late 2024, following the defection of a senior RSF leader. By early 2025, SAF had solidified its authority over most of Sennar and Aj Jazirah states.[78] The conflict has continued to affect Blue Nile and Sennar states through 2025, including ground incursions by Al-Hilu's RSF-aligned SPLM-N faction and drone strikes deep within SAF-held territory.[79] As of early 2026, heavy fighting between factions in southern Blue Nile State reportedly resulted in more than 450 casualties.[80] These dynamics illustrate how shifting front lines continue to pose risks in DNP and its surrounding communities, including through displacement, economic instability and a growing humanitarian crisis. Climate-related impacts, as outlined throughout this profile, compound these pressures.

XXV Many of these IDPs already experienced displacement from initial outbreaks of violence in Khartoum. See IDMC (2025). "Sudan – The World's Largest Internal Displacement Crisis Deepens." Internal Displacement Monitoring Centre. 13 May. 2025. URL: https://www.internal-displacement.org/spotlights/sudan-the-world-s-largest-internal-displacement-crisis-deepens/; Ali, A.M., N. Eltayeb, and J.G. Birru (2025). Two Years of War in Sudan: How the SAF is Gaining the Upper Hand. ACLED. 15 Apr. 2025. URL: https://acleddata.com/report/two-years-war-sudan-how-saf-gaining-upper-hand

Climate Exposure Risk	Gedaref	Sennar	Blue Nile
Risk to Population (Labour) of Extreme Heat			
Risk to Population (Labour and Market) of Increased Floods and Droughts			
Risk of Precip. Variability on Sorghum Production			x
Risk of Precip. Variability on Millet Production			x
Risk of Precip. Variability on Sesame Production		x	
Risk of Precip. Variability on Groundnut Production	x		x
Risk to Livestock of Extreme Heat and Precip. Variability			
Risk of Climate Impacts to Non-Forest Timber Product (not Gum Arabic) Harvest			
Risk of Climate Impacts to Gum Arabic Harvest			

Table 2. Climate Exposure Risk by State under SSP3-7.0 by Mid-Century.[XXVI] Colours indicate future change in risk relative to baseline climate conditions (1995–2014) and current exposure: red = highest increase, orange = next-highest increase, yellow = smallest increase, green = no significant increase identified, x-marked = less/not applicable. (See text for interpretation, and footnotes for data sources and methodology).

XXVI Population exposure to extreme heat based on World Bank's Climate Change Knowledge Platform (CCKP). Population exposure to floods and droughts based on WRI Aqueduct 4.0 Water Atlas and Flood Model. Crop production response to precipitation variability based on IMPACT Model (Siddig et al. 2018) and crop exposure based on Aqueduct 4.0 Food Model. Livestock exposure based on 2017 estimates of the Third National Climate Communication to the UNFCCC and Harvard Dataverse's 2015 Gridded Livestock of the World (Gilbert et al. 2017), while extreme heat and precipitation exposure based on World Bank CCKP and WRI Aqueduct, respectively. Risk of non-forest timber product collection based on sampled site conditions and harvests of B. aegyptiaca in Elmugheira (2021). Risk of gum arabic collection based on Musa et al. (2023) and Sudan's 2016 National Adaptation Plan. See: adelphi (2025). Climate Impact Profiles Supplemental Information. Weathering Risk Programme. URL: https://weatheringrisk.org/en/publication/climate-impact-profile-supplementary-information; Higher Council for Environment and Natural Resources (2022). Sudan's Third National Communication under the UNFCCC. Republic of Sudan. URL: https://unfccc.int/documents/646439; Gilbert, M., Cinardi, G., Da Re, D., Wint, W.G.R., Wisser, D., Robinson, and Timothy, P. (2022). Global Sheep Distribution in 2015 (5 minutes of arc), DOI: https://doi.org/10.7910/DVN/VZOYHM, Global Goats Distribution in 2015 (5 minutes of arc), DOI: https://doi.org/10.7910/DVN/YYG6ET, Global Cattle Distribution in 2015 (5 minutes of arc), https://doi.org/10.7910/DVN/LHBICE, Harvard Dataverse, V1; URL: https://dataverse.harvard.edu/dataverse/glw_4; Siddig, K., Stepanyan, D., Wiebelt, M., Zhu, T., and Grethe, H (2018). Climate Change and Agriculture in the Sudan: Impact Pathways Beyond Changes in Mean Temperature and Rainfall. Regional Working Program Paper 13. International Food Policy Research Institute (IPRI). URL: https://cgspace.cgiar.org/rest/rest/bitstreams/168765/retrieve; Elmugheira, M. (2021). Effects of Livestock Browsing and Illegal Harvesting on Natural Regeneration and Ecology of Balanites Aegyptiaca in Dinder Biosphere Reserve, Sudan. PhD Dissertation, Nelson Mandela African Institution of Science and Technology. URL: https://core.ac.uk/download/pdf/533567488.pdf; Musa, F.I., Sahoo, U.K., Eltahir, M.E., Magid, T.D.A., Adlan, O.E., Abdelrhman, H.A. and Abdelkarim, A.A. (2023). Contribution of Non-Wood Forest Products for Household Income in Rural Area of Sudan – A Review. *Journal of Agriculture and Food Research, 14*: 100801. DOI: https://doi.org/10.1016/j.jafr.2023.100801; Ministry of Environment, Natural Resources, and Physical Development (2016). National Adaptation Plan. Republic of Sudan. URL: https://www4.unfccc.int/sites/NAPC/Documents%20NAP/National%20Reports/Sudan%20NAP.pdf

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