Sudan Climate Analysis in The Context of Conflict

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Context & Rationale

Climate change is one of the greatest challenges facing East Africa, where countries like Sudan are increasingly exposed to rising temperatures, recurrent droughts, and extreme weather events. Despite contributing minimally to global greenhouse gas emissions, Sudan remains one of the most climate-vulnerable countries in East Africa, facing severe water stress, high rainfall variability, and expanding desertification that threaten food security and livelihoods.[1] Multiple vulnerability indices classify Sudan among the countries most at risk from climate variability and climate change. Pastoral and agro-pastoral communities rely on natural rangelands, mobility, and livestock assets as core livelihood pillars.[2] Sudan's livestock sector remains a cornerstone of the national economy, accounting for 34% of agricultural GDP and providing 40% of total employment. This underscores the continuing importance of pastoral and agro-pastoral livelihoods.[3] The increasing occurrence of droughts and heightened rainfall variability in recent decades have significantly strained rain-fed agricultural and pastoral systems, which constitute the main sources of livelihood for rural populations.[4]

Empirical reports indicate that Sudan has experienced considerable variability in rainfall, a rise in average temperatures, an increased incidence of flooding, and recurrent drought events, all of which have exerted substantial adverse effects on agricultural production. Deficient rainfall and droughts reduce soil moisture, disrupt planting and harvesting schedules, and limit water availability for crops and livestock, resulting in lower yields and increased food insecurity. Conversely, excessive rainfall and flooding can destroy crops, cause water logging, accelerate soil erosion, and damage agricultural infrastructure.[5] In addition to climate challenges, armed conflict has severely disrupted farming activities in Sudan with cascading effects across all pillars of food and nutrition security. These repeated shocks erode community coping capacity and weaken anticipatory action, threatening the stability of food systems over time.[6]

Violence leads to the displacement of farmers, destruction of infrastructure, restricted access to cropland, and limited availability of agricultural inputs.[7] Darfur, Blue Nile, and South Kordofan experience recurrent droughts, erratic rainfall, and prolonged conflict, leading to displacement, crop loss, and reduced livestock production. Gedaref, the country's breadbasket, is primarily affected by rainfall fluctuations and occasional flooding, impacting sorghum, sesame, and sunflower production. Overall, the dual pressures of climate anomalies and conflict threaten agricultural productivity, rural livelihoods, and food security.[8]

This analysis provides a comprehensive overview of Sudan's geography, including its climate context and topography; alongside short-, medium-, and long-term drought assessments. It also examines the impacts of drought on croplands, with the aim of deepening understanding of how conflict further affects agricultural systems.

Key Messages

- **Climate variability in Sudan has intensified, with alternating cycles of drought and flooding.** Short and long-term **Standard Precipitation Index** (**SPI**) analyses show near-normal rainfall in 2023, extreme wet conditions and widespread flooding in 2024, and mixed but moderate anomalies in 2025. These patterns highlight a growing climate instability that affects water availability, soil moisture, and agricultural productivity.
- **Key agricultural regions face increasing environmental stress, threatening Sudan's food production.** Areas such as Gedaref, Blue Nile, Sennar, and Darfur which fall under the rain-fed semi-mechanized zone show recurring drought signals and vegetation decline (**Vegetation Condition Index** (**VCI**)), while other regions experience chronic flooding. This variability directly affects cropland conditions and the livelihoods of farmers and agro-pastoralists who rely heavily on rain-fed agriculture.
- **Conflict and climate shocks jointly undermine agricultural systems and rural livelihoods.** Armed conflict has disrupted farming activities through displacement, loss of infrastructure, and reduced access to land, while climate extremes; droughts, erratic rainfall, and floods, further reduce yields of key crops such as sorghum and groundnuts. The combined pressure is worsening food insecurity across multiple states
- Agriculture and livestock are core to Sudan's economy, contributing 22% of GDP and supported by one of Africa's largest livestock populations. Livestock exports, especially sheep and goats worth US $727 million, remain vital for foreign exchange and national food access.[9] To protect these foundations, **Sudan urgently needs climate- and conflict-adaptive programs that restore production, safeguard pastoral systems, and stabilize markets.**[10]

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Glossary

Drought

A drought is a period of abnormally dry weather characterized by a prolonged deficiency of precipitation below a certain threshold over a large area and a period longer than a month.[11]
There are different types of droughts; the two main droughts are hydrological droughts and meteorological drought. In general meteorological drought can lead to hydrological drought affecting surface water bodies. Typically, hydrological drought occurs when a low water supply becomes evident within a water system, such as groundwater resources. In contrast, meteorological drought occurs when dry weather patterns dominate an area and is usually characterized by low precipitation levels.

Standard Precipitation Index (SPI)

The Standardized Precipitation Index is a widely used index to characterize meteorological drought on a range of time scales. The SPI was designed to quantify the precipitation deficit for multiple time scales that reflect the impact of drought on the availability of different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short time scale, while groundwater, stream-flow and reservoir storage reflect the longer-term precipitation anomalies.[12,13]

Normalized Difference Vegetation Index (NDVI)

Normalized Difference Vegetation Index (NDVI) is used to quantify vegetation greenness and is useful in understanding vegetation density and assessing changes is plant health.[14]

Vegetation Condition Index (VCI)

Vegetation Condition Index is used to identify drought situations and determine the onset, especially in areas where drought episodes are localized and ill defined. It focuses on the impact of drought on vegetation and can provide information on the onset, duration and severity of drought by noting vegetation changes and comparing them with historical values. It relates the current NDVI to its long-term minimum and maximum values, allowing for the separation of weather-related components from ecological factors.[15]

Methodology Overview

The drought assessment for Sudan draws on two key indicators; the Standardized Precipitation Index and the Vegetation Condition Index (VCI); covering all 18 states and 189 localities. The analysis is a drought assessment that examines short, medium, and long-term precipitation deficits alongside vegetation stress. In addition, ACLED conflict data were integrated to assess how conflict dynamics compound drought impacts and influence agricultural conditions across the country.

Calculation of SPI and VCI:

Standard Precipitation Index

$$\mathrm{SPI} = \frac{\mathrm{P} - \mathrm{P}^{*}}{\sigma_{\mathrm{p}}}$$

with p* = mean precipitation and σp = standard deviation of precipitation

Vegetation Condition Index

$$\mathrm{VCI} = \frac{\mathrm{NDVI} - \mathrm{NDVI}_{\mathrm{min}}}{\mathrm{NDVI}_{\mathrm{max}} - \mathrm{NDVI}_{\mathrm{min}}}$$

With NDVImin= NDVI minimum and NDVImax = NDVI maximum.

The crop analysis is based on change detection of NDVI for cropland extracted from the ESRI LULC dataset, comparing 2022 (before the conflict and 2025 (during the conflict) using image differencing.

The tabulate area tool was used to calculate the area of livelihood zones exposed to different levels of drought.

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Geography of Sudan

Sudan is the third largest country in Africa covering about 188,606.8 Km^2. It is bordered by Egypt to the north, the Red Sea, Eritrea, and Ethiopia to the east, South Sudan to the south, and Chad, the Central African Republic, and the Democratic Republic of the Congo to the west and southwest (map 1). The climate is mostly arid and includes four main zones. The northern and eastern regions have a desert climate that is very dry, with high temperatures and very little rainfall. The central region has a semi-arid climate with limited rainfall during the summer months from June to September. The southern region has a tropical climate with higher rainfall and clear wet and dry seasons. The wet season lasts from May to October, and the dry season lasts from November to April. This part of the country supports more vegetation and agriculture.

Topography

The northern part of the country is dominated by desert landscapes, specifically the Sahara Desert. It features sand dunes and rocky plateaus. The Nile River runs through Sudan from south to north, providing vital water resources for the country. The Blue Nile and White Nile converge at Khartoum, Sudan's capital. Central and Southern Sudan feature savannas, plains, and some grasslands, with scattered mountain ranges and higher elevations (Map2. The Red Sea coast offers a mix of coastal plains, hills, and mountain ranges, particularly in the eastern parts.

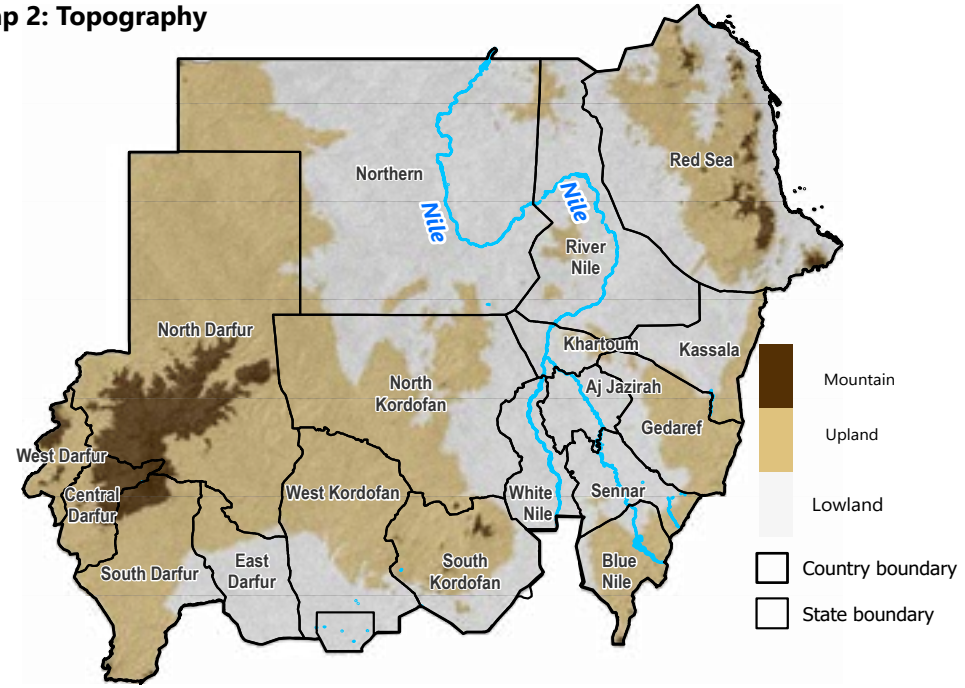
Livelihood Zones

Sudan's agricultural landscape consists of several distinct food-crop zones, including northern riverine small-scale cultivation, Jebel Mara mixed highland farming, southern riverine small- to medium-scale systems, western millet and groundnut production, the rain-fed sorghum belt, and central rain-fed millet and sesame cultivation. Additional key areas include irrigated and wadi-based farming systems, such as central irrigation schemes, wadi cultivation, and flood-recession agriculture, and the south-eastern semi-mechanized agricultural zone. Cash-crop regions include the North Darfur tobacco zone and the North Kordofan Gum Arabic belt, alongside the eastern agro-pastoral sorghum zone.

Beyond these agricultural areas, Sudan also encompasses major agro-pastoral zones such as the western agro-pastoral millet zone, the Kordofan-dominant agro-pastoral zone, the eastern pastoral zone, the eastern Khors agro-pastoral zone, and the eastern agro-pastoral sorghum zone. In addition, the country contains purely pastoral regions, a coastal fishing zone, and an extensive desert zone characterized by arid to hyper-arid conditions, extremely low rainfall, sparse vegetation, and minimal agricultural potential, where livelihoods depend largely on mobility, trade, and seasonal migration rather than crop production.

Map 1: Situation

Map 2: Topography



SPI-Based Analysis of Short- and Medium-Term Drought Conditions

The 3-month Standardized Precipitation Index (SPI) reflects to medium-term moisture conditions and provides a seasonal assessment of precipitation variability. In major agricultural regions, this time scale is particularly useful for capturing soil moisture availability and rainfall anomalies relevant to crop growth. This analysis focused on the SPI period from June to August of the years 2023, 2024, and 2025. This period corresponds to the main growing season for groundnut and sorghum, which are the principal food crops in Sudan.

SPI-3 for 2023

The SPI-3 analysis for 2023 (Map 3 and Map 4) indicates that most regions of Sudan experienced typical rainfall conditions, with only limited precipitation anomalies. Approximately 8% of the national territory recorded a positive SPI anomaly, representing much wetter-than-normal conditions, while about 2% exhibited a negative anomaly, reflecting below-normal rainfall and emerging drought conditions. Overall, the spatial distribution of anomalies suggests a relatively stable hydro-meteorological year with minimal climatic extremes.

SPI-3 for 2024

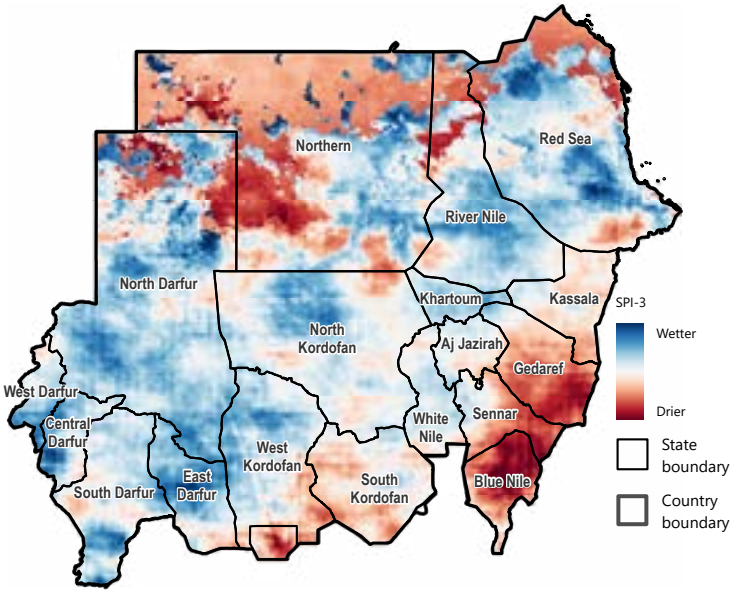
The SPI-3 values for 2024 (Map 5 and 6) demonstrate significant precipitation anomalies across Sudan. Around 4% of the country experienced negative anomalies (below-normal rainfall, indicative of localized drought), whereas approximately 55% of the land area showed positive anomalies, corresponding to above-normal or excessive rainfall. This widespread positive precipitation anomaly is consistent with the flood events reported in several regions of Sudan during 2024, confirming a strong hydrological response to extreme rainfall conditions.

SPI-3 for 2025

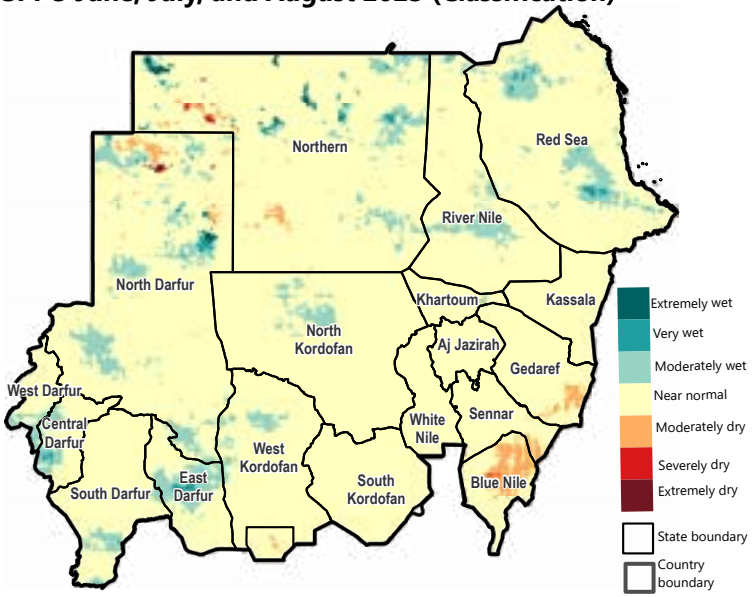
The SPI-3 distribution for 2025 (Map 7 and map 8) suggests limited precipitation anomalies compared with 2024. Positive anomalies were primarily observed in the central part of North Darfur, as well as the northern areas of Northern State and the Red Sea State, indicating a potential risk of localized flash floods in these regions. Conversely, the southern part of Gedaref, southeastern Sennar, and the northern Blue Nile region recorded negative SPI anomalies, reflecting drier-than-normal conditions that could negatively affect agricultural activities during 2024 and 2025.

Overall, the SPI-3 analysis from 2023 to 2025 highlights a clear transition from near-normal precipitation in 2023, to extreme wet conditions and flooding in 2024, followed by mixed but generally moderate anomalies in 2025. These variations underline the increasing climatic variability in Sudan, with alternating drought and flood events posing challenges

Map 3: SPI-3 June, July, and August 2023

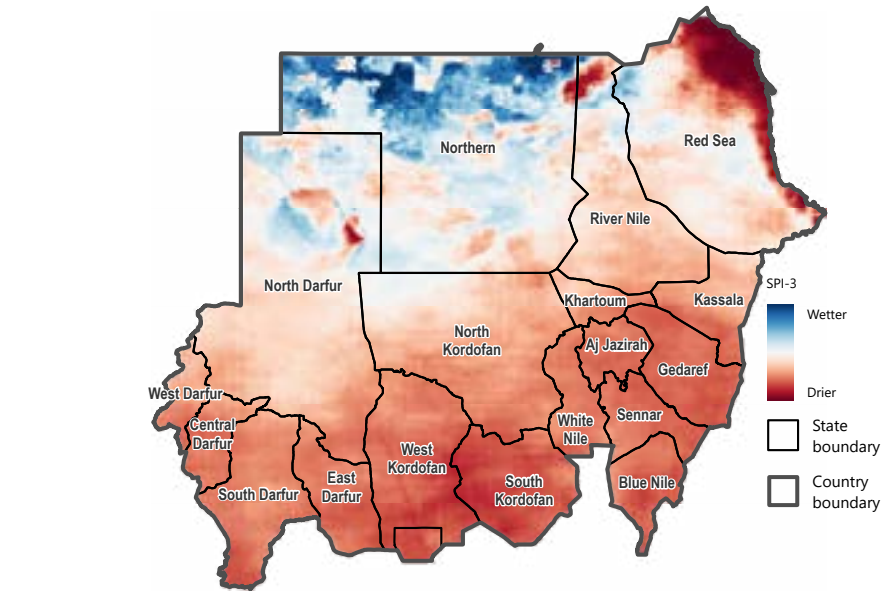


Map 4: SPI-3 June, July, and August 2023 (Classification)

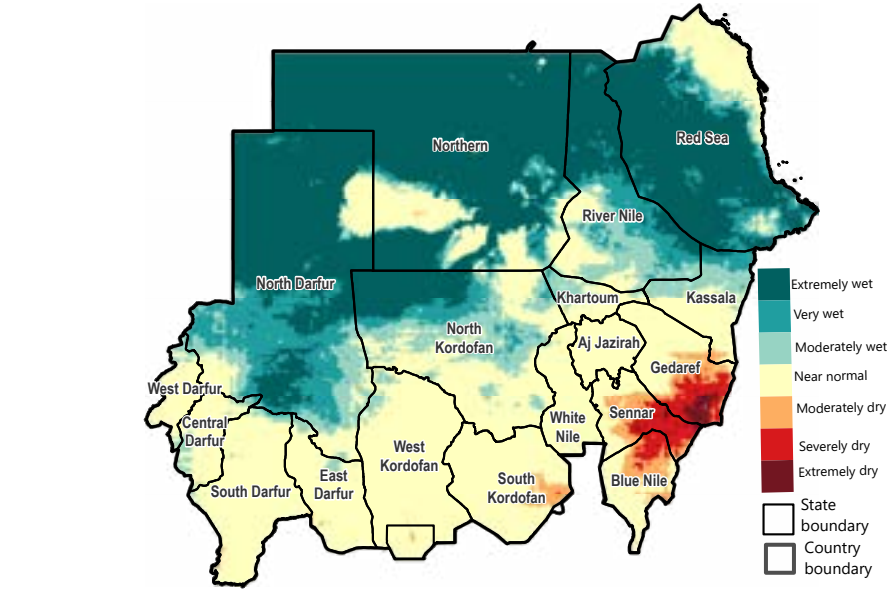


for water resource management, agriculture, and disaster preparedness.

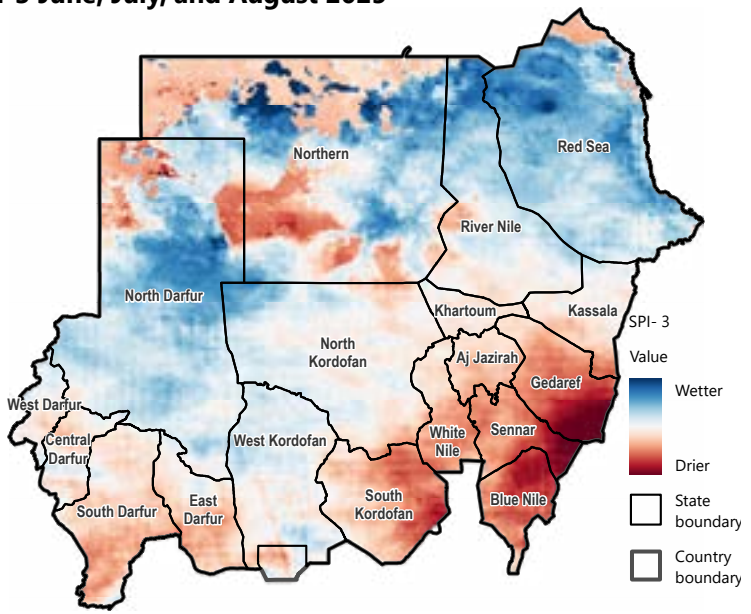
Map 5: SPI-3 June, July, and August 2024



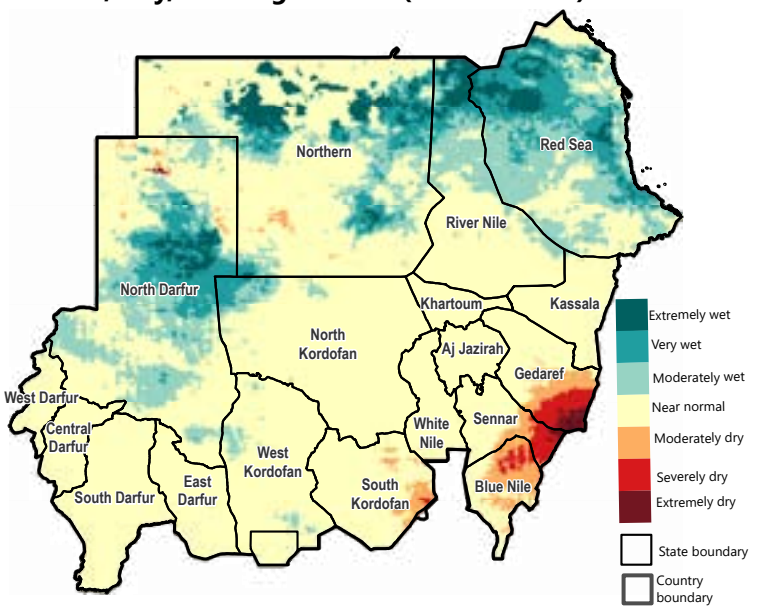
Map 6: SPI-3 June, July, and August 2024 (Classification)



Map 7: SPI-3 June, July, and August 2025



Map 8: SPI-3 June, July, and August 2025 (Classification)



Overall SPI from 1981 to 2024

The 12-month Standardized Precipitation Index (SPI) analysis indicates significant inter-annual variability in Sudan's rainfall patterns between 2023 and 2024. In 2023, the country experienced predominantly normal to slightly below-average precipitation, with limited areas (less than 1%) showing pronounced negative rainfall anomalies and about 34% of the territory recording below-average conditions. Conversely, 2024 was characterized by markedly wetter conditions, with over 50% of the national area exhibiting positive rainfall anomalies and only about 5% showing deficits. The strong positive cumulative rainfall anomaly observed in 2024 aligns with the extensive flooding events reported across Sudan during the same period, highlighting the SPI's effectiveness in capturing large-scale hydro-meteorological trends.

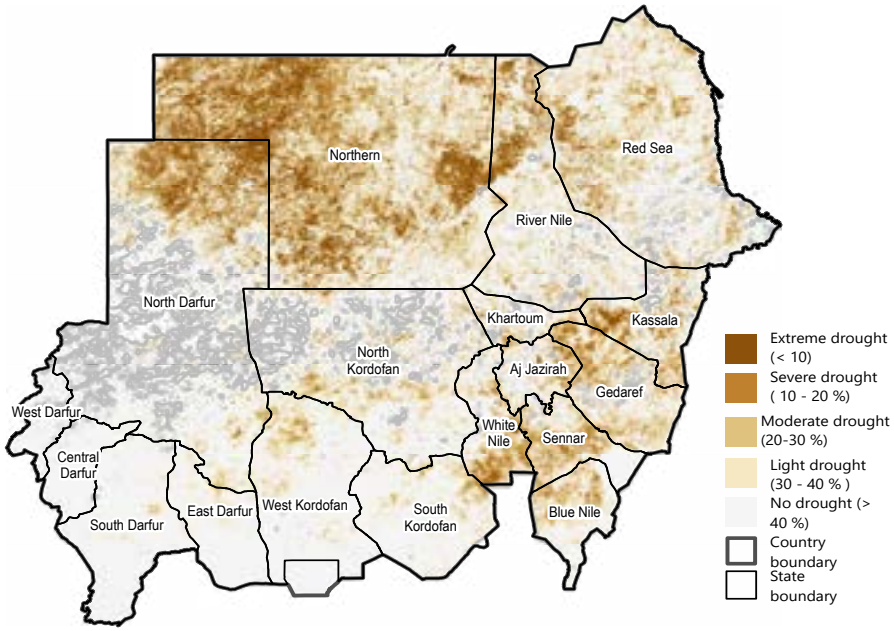
The SPI-12 series from 1981 to 2024 reveals a clear long-term transition from persistent drought toward wetter and more variable conditions. The 1980s were dominated by widespread drought, while the period after 2015 shows increased rainfall and several hydrological surpluses. The extreme wet year of 2023 and continued positive anomalies in 2024 corroborate observed flood events across Sudan. **This analysis highlights the region's growing hydro-climatic variability, emphasizing the importance of integrated drought–flood risk management and climate adaptation strategies.**

Drought Impacts on Cropland Evaluated Through the Vegetation Condition Index (VCI)

The integration of VCI (Map 10) **and cropland distribution data (Map 9) reveals that approximately 25% of Sudan's cropland was affected by drought at varying intensities.** Specifically, 1.4% of cropland was subjected to extreme drought, 8% to severe drought, and 15% to moderate drought during this period. Drought affecting 25% of Sudan's cropland is likely to reduce crop yields, lower food availability, raise staple prices, and weaken household access to nutritious food, especially among rural farming communities, ultimately heightening the overall risk of food insecurity and increasing humanitarian needs.This situation of food insecurity is exacerbated by the ongoing conflict in the country, which has disrupted agricultural operations and weakened farmers' ability to cultivate and harvest. While there are improvements in some areas, the situation still reflects major conflict-related constraints, with wheat, millet, and other key crops performing below their five-year averages in several regions due to limited access to land, inputs, and markets. These reductions highlight how conflict continues to undermine food availability and deepen the existing food security crisis.[16]

Map 9: Cropland

Map 10: Vegetation Condition Index (June to August 2025)



Exposure of the livelihood zone to drought

The figure 1 reveals a highly uneven distribution of land across drought intensity classes and livelihood zones (Map 11), with extreme and severe drought areas varying by more than an order of magnitude between zones.

Desert zone

Deserts have the largest areas under extreme and severe drought (85,000 km^2 each), reflecting hyper-arid baseline conditions rather than episodic events. Low VCI values indicate chronic moisture limitation rather than acute drought.

Agro-pastoral and pastoral zone

Agro-pastoral and pastoral zones are mostly under no-drought conditions (269,000 km^2 and 210,000 km^2). Located in semi-arid to sub-humid zones, these systems are vulnerable to rainfall variability, with moderate-to-severe drought quickly impacting forage, livestock, and household food security.

Agriculture (Food Crops) zone

Food crops show strong drought gradients, from 574 km^2 under extreme drought to 237,000 km^2 under no-drought. Rainfed systems are concentrated in climatically favorable areas, highlighting sensitivity to rainfall anomalies.

Agriculture (Cash Crops) zone

Cash crops avoid extreme drought, reflecting cultivation in moisture-secure zones. High-value crops are located to minimize climatic risk, balancing environmental and economic suitability.

Coastal Fishing zone

Coastal fishing covers 3,400 km^2 under no-drought and is relatively stable across drought levels, reflecting partial decoupling from inland rainfall. Indirect effects from freshwater inflows or salinity may still affect productivity.

Cross-zonal insights

Drought exposure is shaped by climate patterns, ecosystem resilience, and reliance on livelihoods. Deserts zones due to arid conditions are prone to drought, while semi-arid pastoral areas are especially sensitive to changes in rainfall. Agriculture is concentrated in stable, humid zones, showing that vulnerability depends on both drought intensity and ecological sensitivity, particularly under projected climate change.

Map 11: Livelihood Zones

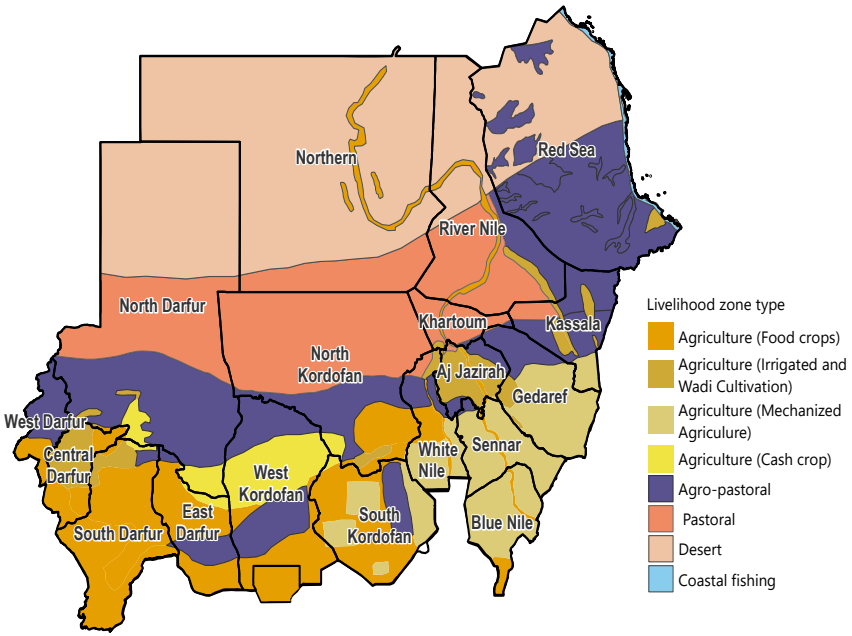
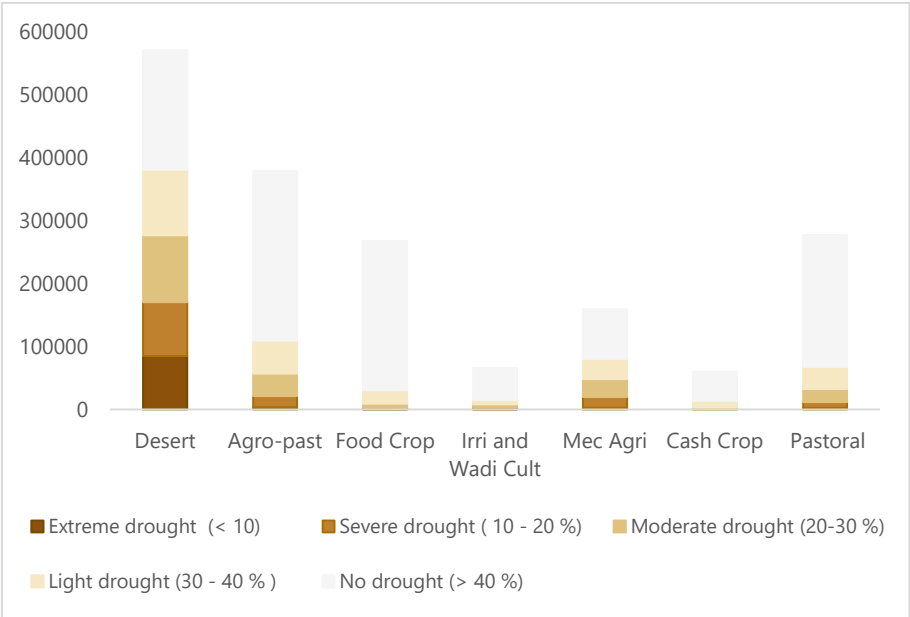


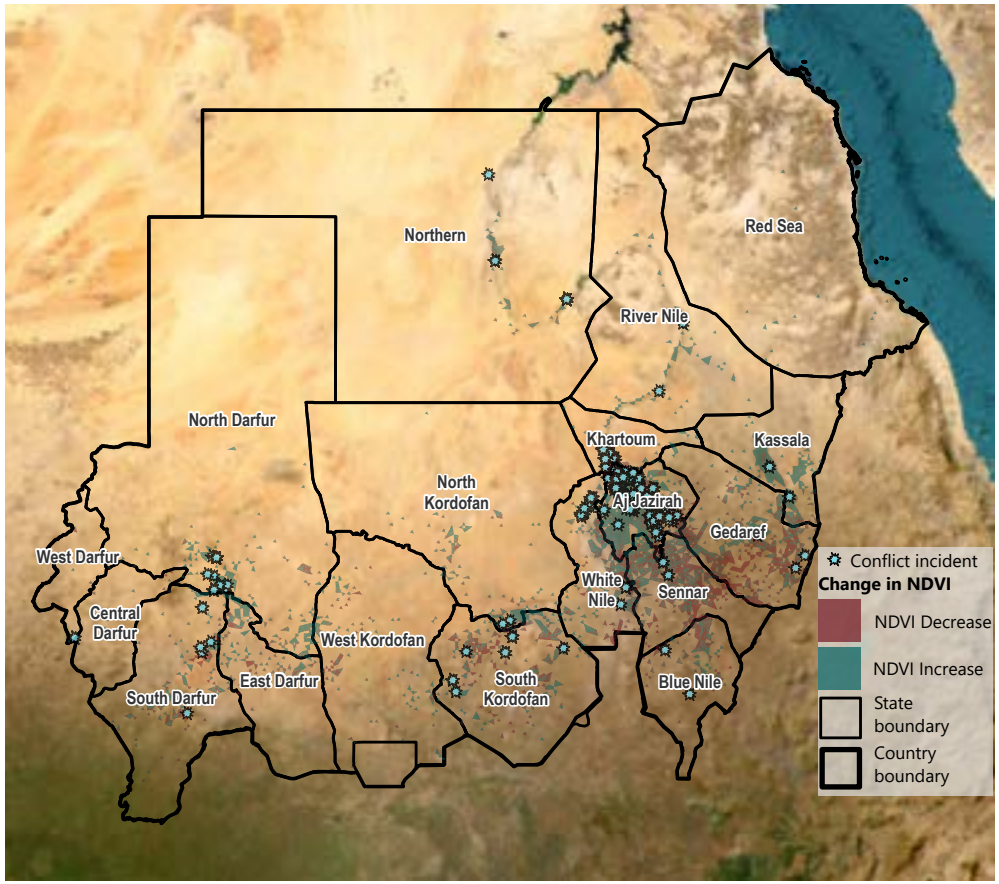
Figure 1: Exposure of the livelihood zone area in Km^2 to drought



Impact of Conflict on Agriculture

The analysis of cropland using NDVI difference images from June 2022 and June 2025 (Map 12) shows that nearly half of the cropland area experienced a decline in vegetation condition between the pre-conflict period (2022) and the conflict period (2025), with the reduction particularly pronounced in zones where conflict incidents were recorded. **The comparison of NDVI values between the two years indicates that about 50% of cropland shows a significant decrease in vegetation greenness, a pattern that reflects reduced chlorophyll activity typically associated with crop stress, limited cultivation, or field abandonment.**

Map 12: Impact of Conflict on Cropland



In conflict-affected settings, such decreases are commonly linked to disrupted agricultural activities, including farmer displacement, restricted access to inputs, and damage to cropland. Conflict incidence data show that the highest levels of violence occurred in Sudan's major agricultural states: Al Jazirah, Sennar, and White Nile, which are central to the country's irrigated and rainfed production systems, meaning that disruptions in these areas likely contributed directly to the observed reduction in crop vigour. The suppressed NDVI decline signals lower crop biomass and expected yields; when it occurs across key production regions during the growing season, it indicates that crops were either not planted, poorly maintained, or harvested prematurely, and that significant livelihood and market disruptions persisted. In parallel, heightened insecurity restricted farmers' movement, further undermining crop production.

Endnotes

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