

Research Article

Impact of Climate Change Vulnerability on Agriculture, Forestry, Water Resources and Range Land in South Darfur State, Sudan

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Abstract

This study was conducted in South Darfur State (SDS) during 2019 with aim to assessing climate change vulnerability by using the INDVI and Aridity Index (AI) to study the impact of climate change on forestry and range species. Three methods used were: (1) Remote sensing method to estimate INDVI and aridity index (AI), (2) Focus group discussion and (3) Key informant interview (KII). According to MODIST and LAND SAT-8 data the results from vulnerability assessment showed that 0.003% of Beliel locality is highly vulnerable, 13.5% is moderate vulnerable, 13.5% is slight vulnerable, while 63.8% from the total area are non-vulnerable. For Merishing locality 48% of the locality is highly vulnerable, 32% moderately vulnerable and 20% as slight vulnerable. In Gereida locality the result showed that most of the locality (82.3%) is non-vulnerable, while only 17.7% from the total area is slightly vulnerable. The main field crops in the targeted localities are Sorghum (*Sorghum bicolor* (L.) Moench), groundnut (*Arachis hypogea*), millet (*Pennisetum glaucum*), okra (*Abelmoschus esculentus*), cowpea (*Vigna unguiculata*), sesame (*Sesamum indicum*), maize (*Zea mays*), roselle (*Hibiscus sabdariffa*) and other vegetable crops. Crop production constraints include; low and erratic rainfall, poor soil fertility, lack of extension services, and poor crop genetic stock. The main tree species in the study area are *Adansonia digitata*, *Acacia melleofera*, *Acacia radiana*, *Hyphaenethebaica*, *Clitropesprocera*, *Acacia nubica*, *Balanites aegyptiaca*, *Ziziphus spina-christia*, *Acacia nilotica*, *Ficus glumosa*, *Tamarindus indica*, *Sclerocarya birrea*, *Hyphaenethebaica* and *Acacia senegal*. The constraints forest sector the absence of alternative source of energy, poverty, violent-conflict, overgrazing, population growth, climate change, mismanagement, gold mining and Agriculture & urban expansion these represent major factors among others that lead to forest degradation. The results showed that the palatable range species are decreasing compared with the previous seasons. The main constraints for range land improvement and animal production in the targeted villages are, unavailability of vaccines, expansion of the cultivated land, scarcity of water for animals and human consumption, tribe conflict and armed robbers. Therefore, the general recommendation for the targeted localities can be summarized in use of improved varieties for field and horticultural crops, improved water harvesting and spreading technologies, improved crop storage, establishment of community forests and nurseries and alternative energy sources.

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Furthermore, climate change could accelerate the spread of malaria, yellow fever and cholera. Although the provision of basic health services and health education will be a necessary element to adaptation.

Keywords

Climate Change, Sudan, Agriculture, Forestry, Beliel, Mershing, Gereida, South Darfur Localities

1. Introduction

The armed conflict in Sudan continued in Darfur, Gezira, Khartoum and Kordofan states, bringing the total number of internally displaced people to 10.9 million - half of whom are estimated to be children [16]. The malnutrition and food security situation remains critical, with most SMART surveys conducted in 36 localities in 2024 reporting Global Acute Malnutrition (GAM) rates above the emergency threshold. Cholera continued to spread, with over 18,000 reported cases and 535 deaths across 10 states. Actual numbers are likely higher due to limited surveillance and reporting from conflict-affected areas [16].

Darfur remains an epicenter of large scale protracted displacement, where most IDPs are unable to meet their basic needs independently. The scale and long-term nature of displacement, which has not been matched by economic opportunities, has exposed displaced people to hardship and uncertainty about their future, which in turn puts additional strains on the limited resources available. The long-term effects of protracted displacement have disrupted and limited access and availability of basic public services such as health and WASH, especially in IDPs camps and resettlements. Among displaced people, women and children are the most vulnerable and at risk of being exposed to communicable diseases, malnutrition, and violence during travel necessary for water and wood collection [4]. According to the Sudan HNO (2018), an estimated 537,833 IDPs, 8,078 returnees, and 278,118 residents are in acute need of humanitarian assistance in South Darfur State (SDS), one of the most populous states of North Sudan with about 30% of the population living in IDPs camps and hard-to-reach areas. The war caused the failures of the life system everywhere in Darfur. Most of the time, people could not produce, trade, migrate for work, or move their livestock around in search of grazing and water, the conflict destroyed people's livelihoods [20].

Sudan has a range of ecosystems and agricultural systems [14]. Throughout much of the country, water resources are limited, soil fertility is low, and drought is common. These underlying conditions are exacerbated by various human pressures. Thus, Sudan is already highly vulnerable to climatic shocks and unless adaptive measures are taken, will become even more vulnerable in the face of future climate change [12]. Sudan's National Adaptation Program of Action states that the major climate-related hazards associated with climate change are droughts and extreme flooding events.

Climate change significantly impacts farming systems, primarily by altering growing conditions, increasing weather extremes, and impacting soil health and water resources. These impacts can lead to reduced crop yields, lower livestock productivity, and changes in farming practices [7]. Studies have shown that temperature increases can accelerate crop maturation rates, leading to reduced grain-filling periods and lower yields for major staple crops, like wheat, rice, and maize. Elevated temperatures also exacerbate evapo-transpiration, reducing soil moisture and increasing water stress on crops [10]. Climate change also affects precipitation patterns, leading to more frequent and severe droughts in some regions, but increased rainfall, and flooding in others. These changes disrupt traditional farming practices and can severely affect crop yields. For example, increased drought frequency and intensity have been linked to significant yield reductions in rain-fed crops. Conversely, excessive rainfall and flooding can lead to waterlogged soils, root diseases, and physical damage to crops [10]. Crop diversification, the practice of growing a variety of crops, is an effective adaptation strategy that enhances resilience to climate-related stresses.

Darfur has lost more than 30% of its forests since Sudan's independence the deforestation is on-going, according to [15]. The forests resource in Central Darfur State and the tree density has gone down from 400 trees per hectare in 1998 to 27 trees per hectare in 2016 [2, 4]. At the present forests resources represent about 45% of the area in Darfur region [15].

There are different drivers of forest degradation and loss in Darfur as Darfur is region of fragile ecosystems, characterized by frequent droughts, and violent-conflict and, as a result, pressing challenges to address the regional priorities of food security, water supply, forests management and public health. The problem of forest degradation & management is very complicated with the lack or absence of the regular and systematic afforestation campaigns by either government institutions or other stockholders. However; throughout the last three-decades with increases of deforestation and decreases of afforestation process the forests resource in Sudan generally and Darfur particularly were seriously degraded resulted from different reasons and factors this including; absence of alternative source of energy, poverty, violent-conflict, overgrazing, population growth, climate change, mismanagement, gold mining and Agriculture & urban expansion this might repre-

sent major factors among others that lead to forest degradation.

The objectives of this paper is to study the climate change vulnerability in three localities in North Darfur State by using the NDVI and Aridity Index (AI) and the effect of climate change vulnerability on forest tree species and range conditions.

2. Material and Methods

South Darfur is situated in the southwest of Sudan and has 21 localities. It borders the states of Central, East and North Darfur, as well as South and the Central African Republic (CAR). South Darfur covers 81,000 square kilometers (the size of United Arab Emirates), with a population density of 27 persons per square kilometer. However, 20 per cent of the population lives in IDP camps/host communities, where the average density is 13,000 persons per square kilometer. The landscape is characterized by lowlands to the south, rising to 791 meters above sea level in the Jebel Marrah (mountainous

region) to the north. The state is traversed by myriads of wadis (seasonally water bodies) that render road travel impossible during the rainy season from July to September. The capital of the state is Nyala, which is the second largest city of Sudan (after the joined cities of Khartoum, Omdurman and Khartoum North) with 834,000 inhabitants [16]. The main stay of South Darfur's economy is agriculture and livestock. Agriculture is rain fed - and with most of the land arable - produces good yields of sorghum and millet for local consumption and export to other states. Cash crops include groundnuts, sesame, roselle (Hibiscus), beans and watermelon. The Jebel Marra Mountains are known for their citrus fruits. Along with livestock (pastoralist make up 10 to 15 per cent of the South Darfur population), agriculture has been the state's main exports, as well as the base for much of Nyala's manufacturing industry, for example the processing of oil from groundnuts and sesame and the production of agricultural tools. The study was conducted in three localities in South Darfur State Mershing, Beliel and Gereida Table 1 and Figure 1.

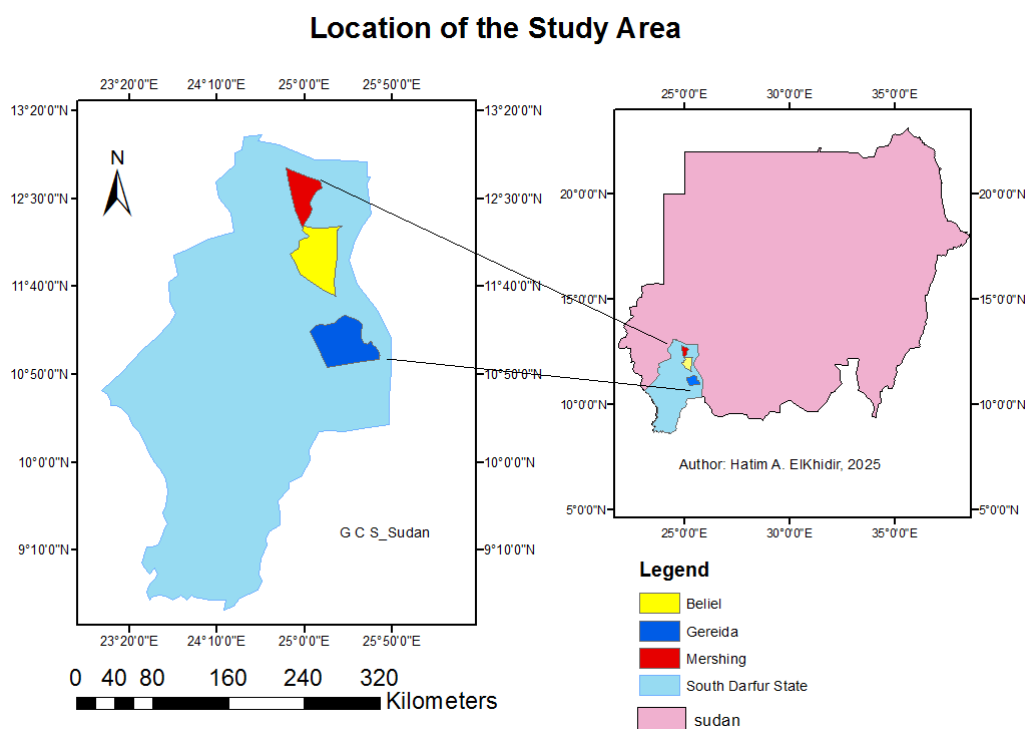


Figure 1. Study area.

Table 1. The targeted villages in Mershing, Beliel and Gereida.

Locality	Villages	Latitudes	Longitudes
Mershing	Gad Elhabob	12.09771	24.93677
	Andur	12.18681	24.95967
	Baba	12.09299	24.99453

Locality	Villages	Latitudes	Longitudes
Beliel	Fiago	12.06239	24.88798
	HilatKeneen	12.08285	24.96310
	Elzawiyagara	12.303208	24.539534
	Amar Gadid	12.47245	24.54322
	Elgardod	12.62853	24.48105
	HilatMima	12.568897	24.484962
	Elkhirwee	12.62872	24.44820
	Almouaro	11.429440	25.321626
Gereida Alsunta	Edan	11.95006	25.12629
	Muilla	11.26684	25.27104
	Abu jelah	11.13029	25.224199
	Jokhana	11.64719	25.173885

3. Methods

For vulnerability assessment and adaptation planning eleven scenes from Land SAT 8 OLI were used (Table 2) for producing land use and land cover maps (LULC). Eleven scenes of LANDSAT-8 OLI_TIRS with the following specification that used in LULC determination classes with the following specification for the study area.

Table 2. Land sat images that used in LULC determination classes for the study area.

SN	Path	Row	Bands	Date of acquisition
2	P177	R050	Band1 - band7	12/23/2018
3	P177	R051	Band1 - band7	12/23/2018
4	P177	R052	Band1 - band7	12/23/2018
5	P178	R050	Band1 - band7	12/21/2018
6	P178	R051	Band1 - band7	12/21/2018
7	P178	R052	Band1 - band7	12/21/2018
8	P178	R053	Band1 - band7	12/21/2018
9	P179	R050	Band1 - band7	12/28/2018
10	P179	R051	Band1 - band7	12/28/2018
11	P180	R051	Band1 - band7	12/19/2018

MODIS data were downloaded to cover the study area for the period 1/1/2008 to 31/12/2019. Products downloaded

include Normalized Difference Vegetation Index (NDVI), 250 m resolution and Land Surface temperature (LST), 1000 m resolution (re-sampled to 250 m) to calculate drought index.

The NDVI algorithm subtracts the red reflectance values from the near-infrared and divides it by the sum of near-infrared and red bands.

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Theoretically, NDVI values are represented as a ratio ranging in value from -1 to 1 but in practice extreme negative values represent water, values around zero represent bare soil and values over 6 represent dense green vegetation.

Calculation of Drought Index features vulnerability of farmers to dry spells and mapping of drought is done through calculating Vegetation Condition Index (VCI), Temperature Condition Index (TCI) and Vegetation Health Index (VHI).

3.1. Drought Index and Vulnerability Calculation

The vulnerability of the study area to drought was assessed using the *Vegetation Health Index (VHI)* framework, a widely used method for monitoring drought and vegetation stress from satellite data. The VHI integrates vegetation vigor and thermal conditions and is derived from two sub-indices: the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI), calculated as follows:

3.2. Vegetation Condition Index (VCI)

The VCI compares the current NDVI to range of values

observed in the same period in previous years. The VCI is expressed in % and gives an idea where the observed value is situated between the extreme value (minimum and maximum in previous years. Lower and higher values indicate bad and good vegetation state conditions, respectively. VCI varies from 0 for extremely unfavorable condition, to 100 for optimizing the formula:

$$VCI = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} * 100 \quad (1)$$

3.3. Temperature Condition Index (TCI)

This index reflects thermal stress on vegetation. It compares the current Land Surface Temperature (LST) to its long-term range. Higher temperatures typically indicate increased water stress, so lower TCI values correspond to poorer vegetation conditions. The TCI is calculated as:

$$TCI = \frac{LST - LST_{max}}{LST_{max} - LST_{min}} * 100 \quad (2)$$

3.4. Vegetation Health Index (VHI)

The VHI combines the VCI and TCI into a single comprehensive index for estimating vegetation health and drought conditions. It provides a balanced measure of both vegetation health and thermal stress. The VHI is calculated as:

$$VHI = \frac{VCI + TCI}{2} \quad (3)$$

3.5. Vulnerability Classification

The resulting VHI values were used to classify the region's vulnerability to climate change, based on established drought severity thresholds. The terms used in this study (e.g., "High vulnerability") correspond directly to drought classes, as detailed in the (Table 3) below.

Table 3. Vulnerability Classification.

Vulnerability Class	Drought Class	VHI Range (%)
Very High Vulnerable	Extreme Drought	0-20
High Vulnerable	Severe Drought	21-40
Moderate Vulnerable	Moderate Drought	41-60
Slight Vulnerable	Slight Drought	61-80
Non-vulnerable	No Drought	81-100

Focus group discussion (FGD) with the beneficiaries in the targeted localities in each locality more than three focus group discussions were established with aim to identify communities perception towards the impact of climate change vulner-

ability on forest cover and range condition beside the past event and the copping mechanism with climate change and their suggestion for important intervention to improve the current situation (Figures 10 & 11). Key informant interview (KII). The objective of the KII isto collect information from the local authorities about the situation of the natural resources management, the past intervention and the gaps in (NRM) and their suggestion to fill these gaps.

4. Results and Discussion

4.1. Land Use and Land Cover for the Targeted Localities

The results of land use and land cover showed that Beliel locality covers about 376,954.4 ha. The cultivated land is estimated as 103,923 ha which represent 27.6% from the total area of the locality. Range and grass land covers area of 123,893 ha which represent 32.9% from the total area while trees and shrubs land cover 104,930 ha which represent 27.8% from the locality area (Figure 2). Water bodies (Wadis, Hafir, Rahad) cover an area of 663 ha which represent only 0.2% from the total area (Table 4).

Table 4. Land use and land cover Beliel, Mershing and Gereida localities in North Darfur State.

Localities	Land use	Area (Ha)	Area (%)
Beliel	Bare areas	212.6	0.1%
	Crops land	103,923.0	27.6%
	Grassland	123,893.6	32.9%
	Settlements	1,985.6	0.5%
	Shrubs land	104,930.6	27.8%
	Water bodies	636.0	0.2%
	Woods land	41,373.0	11.0%
Total area		376,954.4	
Mershing	Cropland	47,768.7	12.4%
	Grassland	257,153.5	66.8%
	Settlements	966.9	0.3%
	Shrubs land	17,704.5	4.6%
	Water bodies	3,001.9	0.8%
	Woodland	58,116.9	15.1%
Total area		384,712.3	
	Cropland	129,133.1	34.7%
	Grassland	86,371.8	23.2%
	Settlements	2,034.9	0.5%

Localities	Land use	Area (Ha)	Area (%)
	Shrubs land	84,187.9	22.6%
	Water bodies	10,243.1	2.8%
	Woodland	60,171.6	16.2%
Total area		372,142.5	

Mershing locality is located northwest of Nyala The capital of the State (Figure 3). The total area of the locality is about 384,712.3 ha. The cultivated area is estimated as 47,768.7 ha which represent 12% from the locality area, the grass land

area is about 257,153.5 ha which represent 66% from the total area while the shrubs and wood land area is estimated as 75.82 ha which represent 19.7% from the total land (Table 4).

Gereda locality is located south of Nyala the capital of South Darfur State. The total area of the locality is estimated is about 372,142.5 ha. The cultivated land is about 129,133.1 ha which represent 34.7% from the total area of the locality (Figure 4). Grass land is about 86,371.8 ha (23.2%), shrubs and wood land 146.542 which represent 38.8% from the total area, while the water bodies covers 10,243.1 ha which represent 2.8% (Table 4).

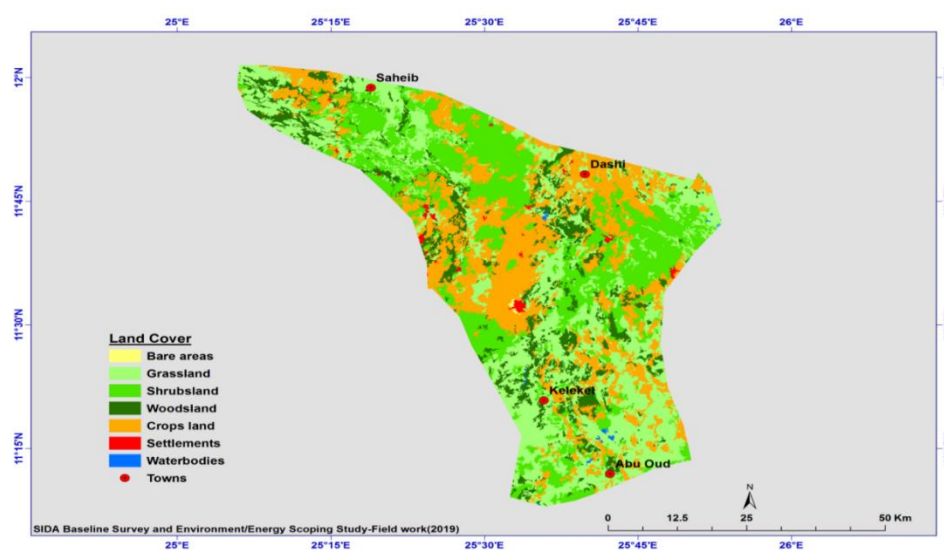


Figure 2. Land Use/Cover areas of Beliel locality.

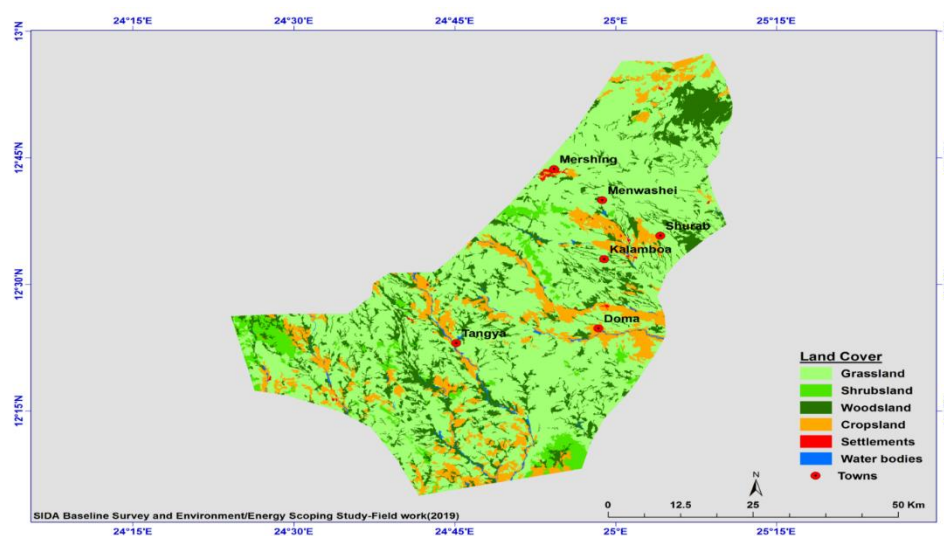


Figure 3. Land Use/Cover of Mershing locality.

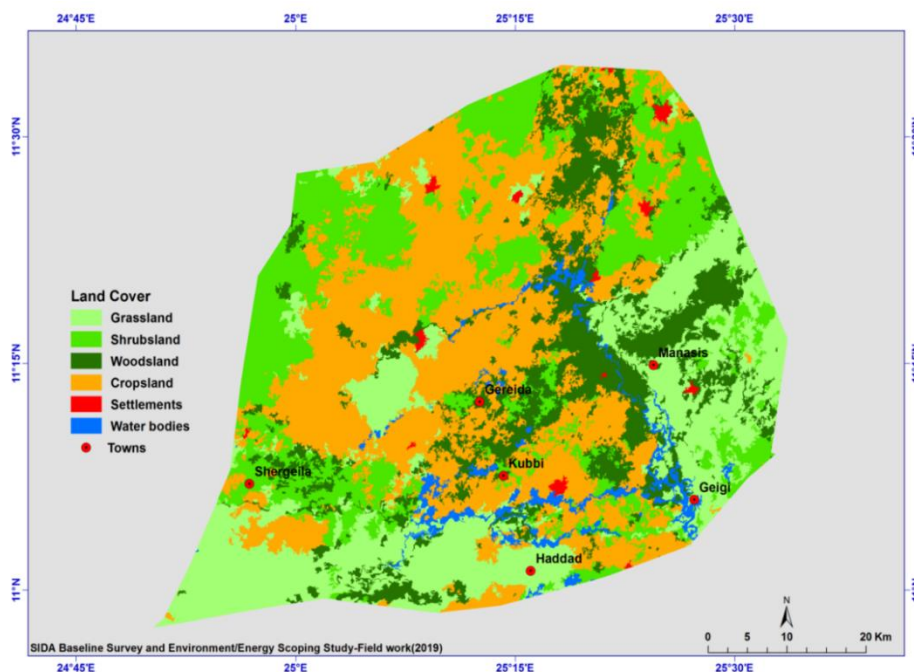


Figure 4. Land Use/Cover of Gereida locality.

4.2. Vulnerability Classification

The results from vulnerability assessment at Belied locality showed that 0.003% of the locality is in highly vulnerable, 13.5% from the total area in moderate vulnerable, 13.5% slight vulnerable, while 63.8% from the total area is non-vulnerable (Figure 5 & Table 5).

However, the results from vulnerability assessment at Mershing locality showed that 48% of the locality is in highly vulnerable, 32% from the total area are classified as moderately vulnerable and 20% as slight vulnerable (Figure 6 & Table 5).

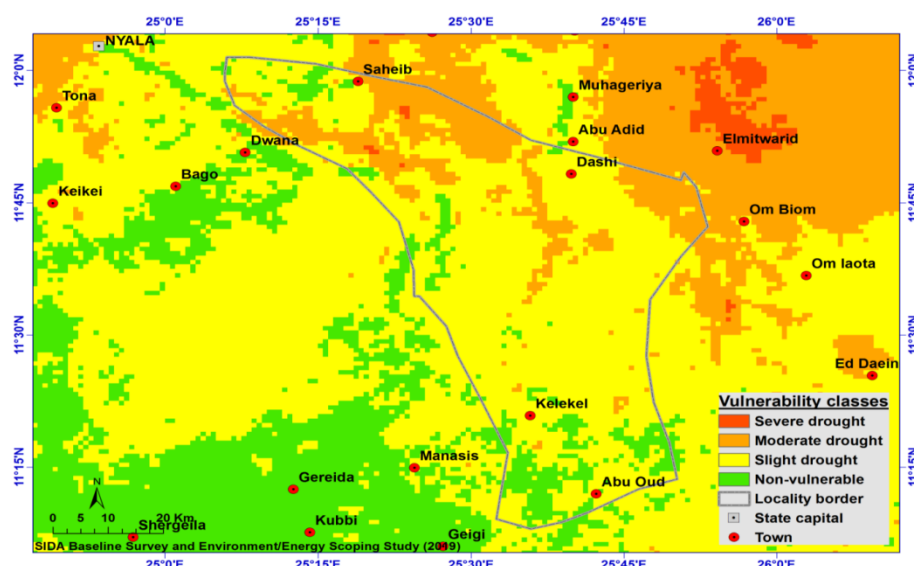


Figure 5. Vulnerability of drought in Belied locality.

The results from vulnerability assessment at Gereida locality showed that more than half of the locality (82.3%) is not vulnerable, while only 17.7% from the total area is affected by

slightly vulnerable (Figure 7 & Table 5).

Many parts of Sudan including Darfur - continue to face disaster, including cyclical flooding, drought and desertifica-

tion. In addition, acute and chronic food insecurity continues to threaten people's lives and livelihoods, and is driven by prolonged conflict, environmental deterioration and disasters.

FAO (2020) reported that climate variability and conflicts are major obstacles to eliminating hunger, malnutrition, and chronic food insecurity. Conflicts create immediate and lasting food insecurity by disrupting production, trade, and access to food. These disruptions, exacerbated by environmental factors, can lead to food shortages, resource competition, and increased social grievances. Food security encompasses four dimensions: food availability, food system, food safety and food accessibility. Climate variability threatens these dimensions by influencing livelihoods, food production and distribution, human health, and changes in market flow and pur-

chasing power [1]. A climate anomaly, particularly rainfall variability, impedes food security, whereas an increase in precipitation enhances it [3]. Therefore, a population already vulnerable and exposed to hunger is more affected by climate change and conflicts.

Widespread deforestation and land degradation (reported by stakeholders and historical data) have likely erased such natural buffering. Ecosystem changes emphasize that climate impacts have a direct translation of irregular rain and heat into vegetation stress for this semi-arid system. These systems are experiencing rising pressure from various stressors that increase their susceptibility. Years of low rainfall and rising temperatures already pushed the system closer to climatic Critical thresholds [19].

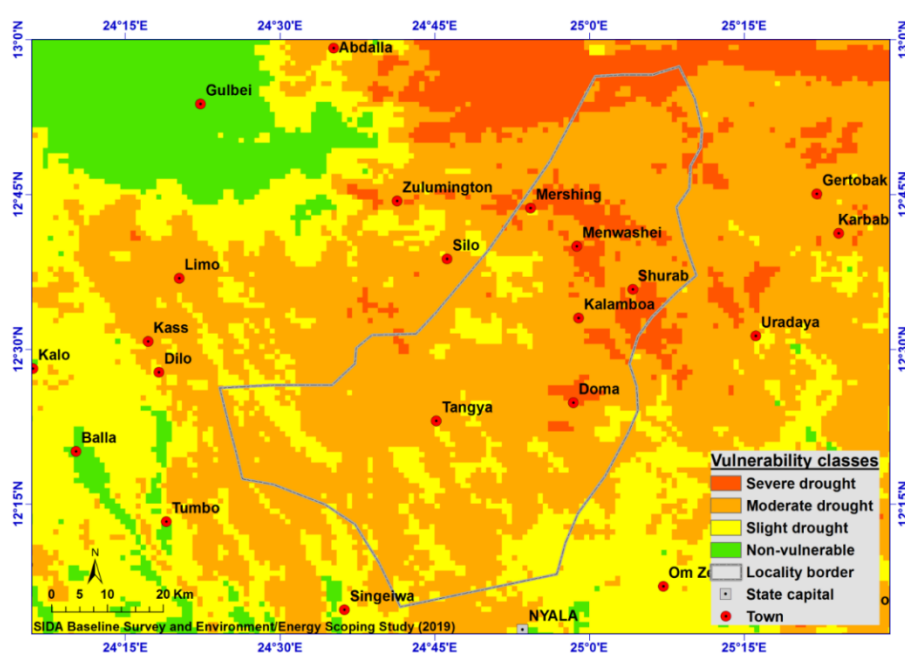


Figure 6. Vulnerability classes in Merishing locality.

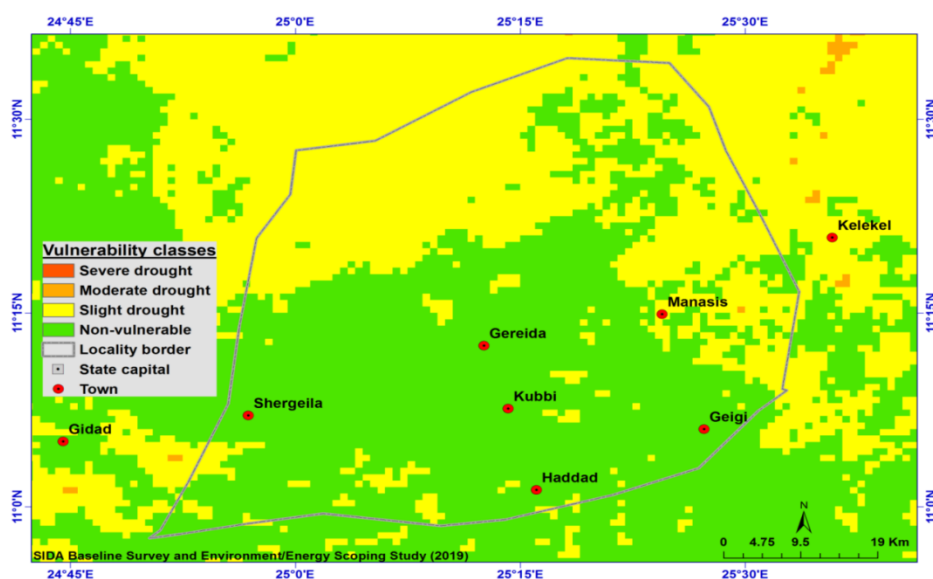


Figure 7. Vulnerability classes in Gereida locality.

Table 5. Vulnerability classes at the targeted localities.

Localities	Vulnerability classes	Area (Ha)	Area (%)
Belied	High vulnerable	9.6	0.003%
	Moderate vulnerable	85,533.9	22.7%
	Slight vulnerable	51,044.1	13.5%
	Non-vulnerable	376,954.4	63.8%
Mershing	High vulnerable	184,495.6	48%
	Moderate vulnerable	124,479.1	32%
	Slight vulnerable	75,737.7	20%
	Non-vulnerable	384,712.3	0%
Gereida	High vulnerable	-	0
	Moderate vulnerable	1.4	0.00%
	Slight vulnerable	65,933.7	17.7%
	Non-vulnerable	372,142.5	82.3%

4.3. Crop Production in the Targeted Localities

Crop production and rainfed farming is the main occupation for more than 80% of the population of western Sudan. The main field crops in the targeted localities are Sorghum (*Sorghum bicolor* (L.) Moench), groundnut (*Arachis hypogea*), millet (*Pennisetum glaucum*), okra (*Abelmoschus esculentus*), Cowpea (*Vigna unguiculata*), sesame (*Sesamum indicum*) Figure 8, maize (*Zea mays*), roselle (*Hibiscus sabdariffa*) and other vegetable crops (Table 6). The cultivated area ranged between 0.25- 5 Mukhamas for each crop (Table 6).

Crop production in the targeted localities facing many challenges and constraints. This constraints as shown in Figure 8 include (1) low and erratic rainfall, (2) poor soil fertility, (3) outbreak of pests and diseases (Mellit head worm, grass hopper), (4) low yielding varieties (5) crop damages by animals.

The results showed that crop yield is not sufficient for household consumption the farmer compensate the yield losses by (1) Free work in towns and big cities (work in building houses), (2) Hand work (rope making), (3) wood collection, (4) collecting and selling forage, (5) Zaaf (Palm leaves) making, (6) selling of small animals (goat, chicken), (7) collect and sell trees fruits (9) traditional gold mining (10) and red brick making.

To avoid climate risk the farmers used some adaption techniques such as Water harvesting (terrace) and early maturing varieties. The main intervention to improve crop production in the targeted localities include; introduction of early mature crop varieties, water harvesting techniques, agricultural machineries, peace building and conflict resolution to avoid the conflicts between the farmers and the pastoralist, use of compost and organic fertilizers, community training on

technical packages to increase crop productivity, improve soil fertility, control of pests and diseases, introduction of Agro-forestry system and crop rotation.

The western Sudan exhibits similar conditions concerning the common features of crop production and food insecurity in Sudan. The majority of people in this region are occupied with agriculture and related activities. In addition to gum Arabic taping and pastoral activities, they cultivate food crops (sorghum and millet) and cash crops (sesame, groundnut, hibiscus and watermelon). The fluctuations of rainfall and desertification combined by widespread crop diseases have led to difficult management of field crops [6]. Recently, the western Sudan has suffered from low crops productivity [5]. Consequently, rural people have suffered from continuous deterioration in their food availability and food consumption as well. This creates a higher food deficit in this region.

The demand for food in the Sudan is projected to grow due to a growing population and growing incomes. Staple food demand, consisting of cereals and roots, is projected to grow from 6.5 million tonnes in 2010 to 10.1 million tonnes in 2030, dairy products from 6.3 to 9.7 million tonnes and sugar from 0.9 to 3.4 million tonnes from 2017 to 2030, demand for these three products is projected to increase by 35, 56, and 157 percent, respectively [9]. Moreover, demand for fats and meat products will increase by 100 percent and 22 percent, respectively, between 2017 and 2030. On the production side, staple foods, dairy products, sugar, fats, and meat products are projected to increase by 6.8, 56, 21, 14, and 23 percent, respectively. Although remaining gaps could be filled with imports, this would add to challenges at the national level for the government budget and trade deficits, as well as the international challenge of making adequate supplies of food available to a growing population worldwide.

Table 6. The main field and vegetables crops and cultivated area Mukhamas.

Crops	Area (Mukhamas)
Mellit	2-5
Sorghum	1-3
Roselle	0.25, - 0.5
Cowpea	1
Groundnut	2-3
Sesame	1-3
Watermelon	1-2
Okra	0.25-1
Corn	0.125-0.5
Tomato	0.125-0.5
Snake cucumber	0.5-1

Crops	Area (Mukhamas)
Hot pepper	0.5
Soya beans	

1 Mukhamas = 0.75 ha



Figure 8. Sesame production in Gereida locality.

4.4. Impact of Climate Vulnerability in Forest Cover in the Targeted Localities

In Beliel locality there is three reserved forest with total area of about 61 ha (145.18) feddan (Table 7). The majority of the interviewers have access to the forest land for collection of fire wood and building materials in after getting the permission from forest authorities. The main tree species in Belail locality are Baobab (*Adansoniadigitata*), Kitir (*Acacia mel-leifera*), Seyal (*Acacia radiana*), Doom (*Hyphaenethebaica*), Usher (*Cliotropesprocera*), Laot (*Acacia nubica*), Higlig (*Balanitesaegyptiaca*), Sidir (*Ziziphusspina-christia*), Sunt (*Acacia nilotica*), Gomeiz (*Ficusglumosa*), Ardeib (*Tamarindusindica*), Humeid (*Sclerocaryabirrea*), Doom (*Hyphaenethebaica*), Hashab (*Acacia senegal*), Arad (*Albizia-amara*), Haraz (*Fedherbiaalbida*), Daleib (*Borassusaethiopum*), Gideim (*Grewiatenax*), Habil (*Combretumspp*) So-bagh), Gafal (*Commifora African*), Goghan (*Daspyrosmespiliformis*), Abanous (*Dalbergiamelanoxylon*), Kadad (*Dichrostachyscinerea*). The result shows that the main source of energy in the targeted villages depend 100% on firewood and charcoal in their daily need for energy. They walk for 3-10 km for collecting firewood. The community is aware about using improve stoves they use Elsurur and Azaa stove. The number of people who use the improved stove is ranged between 1-30% in the targeted villages. The liquid petroleum gas (LPG) is not available in the locality the population depend 100% on forest biomass as a main source of energy. The main constrains for forest improvement in the targeted villages (1) Illegal trees cutting, (2) Agricultural expansion on forest and range land, 3) low rainfall and lack of the natural regeneration;(4) Intensive tree cutting for cocking and lighting and 5) intensive animal browsing.

From the communities point of view the main intervention

in the forestry sector should address the following issues (1) encouraging to establish community forest, (2) using of alternative energy sources to reduce the dependency on forest biomass (3) Introduction of agro-forestry systems, (4) Establishment of villages nurseries, (5) provisos of improved stoves, (6) establishment of community forestry and (7) provision of tree seedlings.

Table 7. The main reserved forest in Beliel locality.

Type	Area	Species
Hashab Forest	6	Hashab, Kitir, Higlig
Hashab Forest	30	Hashab, Kitir, Syal, Higlig
Hashab Forest	25	Hashab, Kitir, Arad, Gideim

The results showed that the communities in the targeted villages have idea about climate change such as the shortage in rainfall in some years and floods in other years. The area was affected by climate change hazard which is resulted in poor grazing and browsing sources, drought and desert creep. The grazing resources in the locality is not enough and the pastoralist migrate to far areas searching for good fodder and palatable range grasses and sometimes they collectforage from browse shrubs. The results shows that the palatable range species are decreasing compared with the previous season. The most palatable species that found in the targeted localities were Abu Asabe (*Dactylocteniumaegyptium*), Difra (*Echinocloacolonum*), Haskaneet, Hantout (*Ipomoea sp*), Om Fraw (*Digitariaadsendens*), Abu Jigra (*Bracchiariasp*), Koreib (*Sporobolusfestivus*), Garagoub (*Spermacocechaetoccephala*), (*Chlorissp*), FurtElarnab (*Crotalaria spp*), Shilini (*Zorniaaglochidiata*), Bugeil (*Blepharislinarifolia*), Direisa (*Tribulusterrestris*). In contrast the unpalatable species were increased. The unpalatable species that found in the targeted area were, Kawal, (*Cassia tora*) Nada (*Abutilon sp*), Soreib (*Cassia sp*), Hirabhousa (*Acanthospermumhispidum*), LisanElteir (*Amaranthussp*), Sana maka (*Cassia senna*). The animal types in the targeted villages weregoats, sheep, donkeys, chicken, cows and camels. The main sources for animal feeding during the rainy season is the natural range land, while in the dry season the pastoralist depend on crop residue, dry grasses straw, concentrates (sesame and groundnut cake) and fodder trees. The main constrains for range land improvement and animal production in the targeted villages are (1) Unavailability of vaccines, (2) Expansion of the cultivated land into range lands, (3) scarcity of water for both animal and human consumption and (4) tribe conflictand armed robbers. The ranking of the constrains according to their negative effect from community point of view include (1) Unavailability of forage, (2) low quality forage, (3) decrease in range lands area due to agriculture expansion, (4) decreased range productivity, (5) significant increase in human and animal

population. The possible intervention to improve the range condition in the targeted locality were (1) Reseeding of palatable range species, (2) Peace building and conflict resolution (3) establishment of fire lines network, (4) growing of perennial legumes range species, (5) Seed broadcasting, (6) improvement of livestock breed (7) introduction of water harvesting techniques (Figures 9 & 10).



Figure 9. Focus group discussion.



Figure 10. Focus group discussion.

4.5. Impact of Climatic and Non-climatic Factors and Adaptation Strategies on Natural Resources in South Darfur State

Climate change significantly impacts farming systems, primarily by altering growing conditions, increasing weather extremes, and impacting soil health and water resources. Climate variability and conflicts are major obstacles to eliminating hunger, malnutrition, and chronic food insecurity [8]. Conflicts create immediate and lasting food insecurity by disrupting production, trade, and access to food. These disruptions, exacerbated by environmental factors, can lead to food shortages, resource competition, and increased social grievances. Food security encompasses four dimensions: food availability, food system, food safety and food accessibility.

In the current study, according to the focus group discussion (FGD) and key informant interview with the local

communities and community leaders in the targeted localities they stated that " the climatic factors that affect agricultural sector in the targeted localities include; low and erratic rainfall and rising temperature (Figure 11). The non-climatic factors which affect agricultural production include; soil erosion and land degradation, spread of pest and diseases especially millet head worm, striga, locust and grass hopper, poor crop genetic stock and poor extension services.

These results are in line with the finding Sudan's First and Second National Communication as well as the NAPA from 2007, who documented how climate change is amplifying and increasing the frequency of many of the climate related hazards already affecting Sudan. An impact of climate change is an increasing frequency of extreme flooding events caused by an increase in intensity of rainfall both during the rainy season (seasonal flooding) and in rainstorms.

Rainfall has always shown high variability in the Darfur States, recent years have seen this pattern intensify. For example, in North Darfur, 20 of the 25 driest years on record have occurred since 1972, threatening agricultural and livestock production, particularly in North Darfur [13]. Across the northern and western areas of the region, 40% of harvests currently fail on average; by 2050, it is expected that 70% of harvests are likely to fail on average.

In South Darfur, if climate variability and overexploitation of resources are not kept in check, a few of the present livelihood systems would have to experience transformation to avoid collapse. For example, if rain fed agriculture continuously fails, societies would have to adopt other livelihoods (e.g. irrigated agriculture wherever feasible, value-added pastoral systems, or income from off-farm livelihoods) in order to remain resilient. This would entail the adoption of new practices and rebuilding institutions. What really matters is that resilience isn't just about returning to how things were before a crisis. It's about learning, adapting, or even changing the system so it can keep working under new conditions.

South Darfur has a less extreme climate than other areas of Darfur, the region will still face more erratic rainfall and more frequent dry spells. Contour maps between isohyets in 1946-1955 and 1976-1985 show that 400 mm of rain have shifted southward of Nyala and maximum rainfall in the Marrah Mountains has decreased from 900 mm to 600 mm per year. This has led to a reduction in seasonal stream levels and a decline in crop yield. Should these trends continue, South Darfur will likely experience a 40% harvest failure rate by 2050 (South Darfur State NAP Committee 2013).

For forestry, range lands and animal production Figure 9. The results showed that the major climatic factors include; low rainfall, higher temperature and sun shining, the no-climatic factors which affect the forestry and range land sector include soil erosion, tree cutting, over grazing, expansion of cultivated land and spread of animal diseases. The impacts of these factors include; desertification, forest and range land degradation, shortage in animal feeds, and decrease of desirable plant species and increase in plant invaders.

The adaptation strategies from the farmer's point of view include; establishment of community forest, introduction of improve stove and solar systems and changes in animal types.

This results are in line with the finding of [17, 18]. Agricultural activities constituted the back-bone of the national, region and local economy of Sudanese people, and a main source of livelihood system for the people in Darfur region. In last four-decades the demands for food security has increase intensely resulted from population growth, led to increase demands for crops production therefore the cultivation land has been extended in the recent years, on the forest areas. Therefore, most of the forestland was replaced by agricultural-land. Moreover; the rapid population growth in the big cities, the absent or decrease in the size of rural areas and the needs for new housing drove the authorities to expand and construct a new housing plan on the agriculture land this complicated situation led to deforestation in the region.

Animal production is also threatened. Shifting climates may hasten the disappearance of palatable rangeland species such as *Blepharisternia* (Beghail) and *Dactyloctenium aegyptium* (Abu Assabi) and appearance of other invasive

species, with overgrazing adding further stress. Migrants from the North as well as refugees from neighboring countries are adding additional stress to rangelands.

The water sector in South Darfur was highly affected by climatic and non-climatic factor this lead to drought in some years and flooding in other years, the adaptation strategies include soil and water conservation by using the water harvesting techniques such as traces, dams, rehabilitation of the degraded lands and maintain the drainage systems. Adaptation in the water sector should include the establishment of rain gauge stations to monitor and provide hydrological information. This should coincide with the maintenance of existing reservoirs and rehabilitation of the water basin infrastructure to increase water storage capacity.

The health sector was highly affected by climatic and non-climatic factor beside the war and tribal conflict. In general the sector facing many challenges such as poor services facilities, lack of medicines, poor training services and staff capacity building all this factors lead to spread of diseases, male nutrition and death.

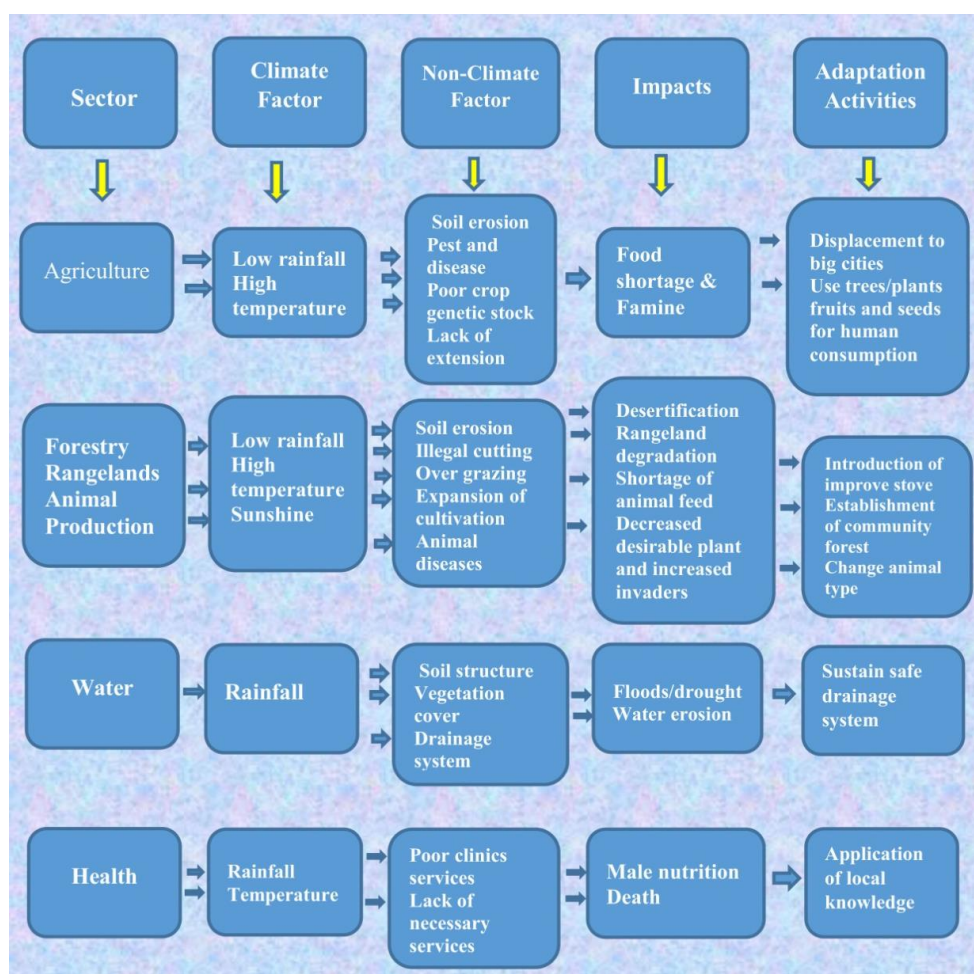


Figure 11. Impact of climate change vulnerability on agriculture, range, forestry, livestock, water and health sectors.

4.6. Climatic and Non-climatic Events in the Targeted Localities in South Darfur State

Adaptation to climate change needs to be strongly rooted in the overall Sudanese development context. For example, climate-change related impacts on rangelands can lead to a potential deepening of resource-based conflicts among pastoral, transhumant and farmer communities - adaptation interventions will need to take this dynamic into account to promote equitable, advocacy-based interventions that incorporate new technology, better practices and conflict resolution strategies. Also, more frequent droughts increase food insecurity differently among rural communities that can only be effectively addressed through the kinds of state-specific adaptation interventions that are developed relative to specific state circumstances.

In the current study, according to the focus group discussion (FGD) and key informant interview with the local communities and community leaders in the targeted localities they stated that " the area experiences successive drought

years in 1964, 1972, 1975, 1983, 1985, 1992 and 1995 beside the war in 2003, the consequences of all this factors include; wind storms, shortage of drinking water, shortage of foods, loss of tree cover, losses of livestock and crop failure. The coping strategies adopted by the local communities include; displacement to the bigger cities as IDPs, using of herbs and tree fruits as food during the famine periods and digging ants' houses searching for stored grains.

These results are in line with the finding of Sudan's First and Second National Communication as well as the NAPA from 2007, have documented how climate change is amplifying and increasing the frequency of many of the climate related hazards already affecting Sudan. An impact of climate change is an increasing frequency of extreme flooding events caused by an increase in intensity of rainfall both during the rainy season (seasonal flooding) and in rainstorms (flash flooding). According to the World Bank's Natural Hotspots Study, Sudan has 29% of its population in areas at relatively high risk from multiple natural hazards.



Figure 12. Climate change events, impacts consequences and coping strategies in the targeted localities.

Local communities in South Darfur have mostly relied on coping mechanisms rather than long-term adaptation. As

shown [Figure 12](#), strategies such as migration, eating marginal food sources, or collecting reactive water sourcing from unconventional supplies, are short-term survival responses to extreme drought. Even though these actions help in the current time, they do little to build lasting adaptive capacity and may even become harmful if they reinforce dependence on crisis-driven measures. Resilience theory warns that systems risk being locked into maladaptive regimes in undesirable situations unless deep vulnerabilities are fixed [5]. That is to say, adaptation alone may lock communities into a cycle of vulnerability, particularly when it reinforces short-term coping at the expense of transformative change. Conversely, conscious adaptation practices such as improved water harvesting, agricultural diversification, and sustainable grazing increase resilience. Other dry land data from such regions as dry areas in Sudan suggest that actions such as rainwater collection and control over overgrazing can enhance vegetation resilience under climate stress significantly [1]. Such adaptive measures build adaptive capacity the ability of actors to adjust to shocks within safe thresholds.

A resilience-based approach also prioritizes the concept of threshold and transformation. As [11] demonstrated, ecosystems could lie in different basins of attraction; transformation refers to converting the system into a considerably new basin when conditions currently prevailing prove unsustainable. [5] Outlines transformability as the potential of creating a new system when ecological and societal frameworks make the existing system unsustainable. In North Darfur, if climate variability and overexploitation of resources are not kept in check, a few of the present livelihood systems would have to experience transformation to avoid collapse. For example, if rain fed agriculture continuously fails, societies would have to adopt other livelihoods (e.g. irrigated agriculture wherever feasible, value-added pastoral systems, or income from off-farm livelihoods) in order to remain resilient. This would entail the adoption of new practices and rebuilding institutions.

What really matters is that resilience isn't just about returning to how things were before a crisis. It's about learning, adapting, or even changing the system so it can keep working under new conditions.

Abbreviations

AI	Aridity Index
CAR	Central African Republic
FGD	Focus Group Discussion
GAM	Global Acute Malnutrition
IDPs	Internal Displaced Peoples
KII	Key Informant Interview
LPG	Liquid Petroleum Gas
LST	Land Surface Temperature
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Differences Vegetation Index
SDS	South Darfur State

TCI	Temperature Condition Index
VHI	Vegetation Health Index

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Conflicts of Interest

The authors declare no conflicts of interest.

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