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Research Article

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

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Abstract

Climate change and the conflicts in Darfur have severely impacted crop production, forestry and range land which lead to sever implications in household income, safety, coping strategies, and overall food security. The current study was conducted in three localities in West Darfur State (WDS) during 2019 with aim to asses' climate change vulnerability by using the NDVI and Aridity Index (AI) and to study the impact of climate change on crop production, forestry and range species in the targeted localities. Three methods were used (1) Remote sensing method (2) Focus group discussion and (3) Key informant interview (KII). According to MODIST and LAND SAT-8 data 87% from El Geneina locality area was classified as non-vulnerable and 13% as slightly vulnerable. Kerenik locality is classified as non- vulnerable to climate changes. 0.5% from the locality area is classified as moderate vulnerable, 13.3% as slightly vulnerable, while 86.2% from the total area was classified as non-vulnerable. For Sirba locality 87.5% of the locality is classified as non-vulnerable, 12.3% as slightly vulnerable and 0.2% as moderately vulnerable. The results from focus group discussion (FGD) and key informant interview showed that the crop production, forest cover and range conditions were highly affected by climate change. The targeted localities experienced drought spells during the periods 84, 85, 86, 85, 2002 and 2018 beside 2003 war. The consequences include; shortage of water, shortage of foods, dust storms, bush fires, crop failure, dead of trees, loss of livestock, food gap, famine and death of children and elder people. In response to the challenges of climate change, households adopted many coping strategies which include: migration to big cities, selling assets, borrowing money, reduce food consumption, requesting social support and use of seeds of grasses and trees as famine foods. The recommendation that suggested by the local communities to improve crop production include; provision of improved seeds, pesticides and fertilizers, mechanization especially intermediate technologies, strengthen ofagricultural extension. For forestry sector the recommendation include; establishment of village nurseries and community forestry, shelter belts and wind breaks, provision of improved stoves and solar energy. For range and forage sector the recommendation include; planting and protecting of fodder trees, seed broadcasting, provision of veterinary services and capacity building in range improvement and management.

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Keywords

Climate Change, NDVI, Vulnerability, West Darfur, El Geneina, Kerenik, Sirba Localities

1. Introduction

West Darfur is one of five comprising the Darfur region. It had an area of 79,460 km ² and an estimated population of approximately 1,007,000. It borders North and Central Darfur. West Darfur has been the site of much of the ongoing Darfur conflict. It falls into a low rainfall savannah zone, an ecosystem rich in seasonal valleys and tributaries that can sustain forests, rangelands, and agriculture. There is large variation in rainfall within the state, with areas in the south receiving nearly 500 mm of rain per year and areas in the north receiving less than half of that amount [26]. The Paleozoic sandstones provide groundwater resources that have sustained the area during dry years. Approximately 80% of the state's economy is based on agriculture and livestock production. Farmers produce a diverse set of cash crops that include cereal crops, oil crops (groundnuts, sesame), legumes, vegetables, and horticultural crops (mango, citruses etc.).

West Darfur has a history of chronic food insecurity. A household health survey conducted in 2006 found that it is the most food insecure region in Sudan with greater than 40% of the population unable to obtain a health daily diet. The region will experience increasing temperatures, increasing rainfall variability, and higher drought frequencies. Combined, these effects will adversely impact crop yield, lead to further deterioration of rangelands, and further deplete groundwater resources [17].

In West Darfur, tension and conflict between the indigenous Darfuri farming people and the nomadic herder population is the main source of the significant displacement in the state. Inter communal tensions are commonly caused by competition over land and natural resources. The main conflict triggers include accusations that land is occupied illegally by Arab nomads, control over water sources, and pasture and crop destruction during the farming season (November and December) by animals owned by nomadic herders. Problems relating to land tenure and the management of natural resources are exacerbated by differing customary, statutory, and religious legal systems of ownership [23].

Climate variability and climate change are likely to intensify the desertification of arable areas. It also predicts that the humid agro-climatic zones are likely to shift southward, rendering areas of the north increasingly unsuitable for agriculture. In addition, crop production is predicted to decline substantially for both millet and sorghum, because of decreasing rainfall and increasing variability in its distribution [16].

Climate change causes food insecurity through its adverse effects on agricultural production and food availability [14]. Due to significant population growth and stagnation in food production, climate change poses major significant threats to food security in Africa [20]. Moreover, civil conflicts impede food security in 71 developing and least-developed countries [14]. Thus, the repercussions of climate change are larger in countries that are vulnerable to conflicts. In the same vein, armed conflicts undermine food security in West African countries [22].

Climate change is expected to affect Sudan's water resources through reduced groundwater recharge brought about by decreased precipitation and/or increased temperatures and evaporation. It has been shown that soil moisture is also likely to decline under future climate change. When coupled with increased water consumption, population growth and high rainfall variability, these effects mean that the country could face a serious water crisis [5].

The aridity index (AI) is a crucial metric for understanding the climatic conditions of an area, particularly in arid and semi-arid regions. It is defined as the ratio of annual precipitation to potential evapo-transpiration (PET), providing insight into the dryness of the environment [1, 2]. The AI is calculated using the UNEP aridity index formula, which helps in classifying the degree of aridity experienced in various geographic areas [1]. Arid zones are typically characterized by excessive heat and variable precipitation patterns, which significantly affect local ecosystems and human activities [5]. The aridity index serves as a key indicator for evaluating climate-related challenges, including water scarcity and desertification, impacting both agricultural productivity and biodiversity in these regions [18, 19]. Understanding the AI is particularly important for developing adaptive strategies in response to climate variability and changes.

Generally, there is many climatic and non-climatic factors contributing to West Darfur vulnerability such as severe poverty levels, lack of income diversity, lack of agricultural inputs, mismanagement of resources, over-cultivation of land, fragile land or water resources, poor soil fertility, deforestation, conflict over natural resources, poor extension services, displacement of communities, Poor sanitation or health services. The objectives of this paper is to study the climate change vulnerability in three localities in West Darfur State (WDS) by using the NDVI and Aridity Index (AI) and to study the effect of climate change vulnerability on crop production, forest tree species and range conditions.

2. Material and Methods

The state of West Darfur is located in the far west of Sudan and has eight localities. It borders the states of North Darfur to the northwest and Central Darfur to the southeast, as well as Chad and the Central African Republic (CAR) to the West on a 750 kilometers long border. The state covers 23,550 square kilometers with a population density of 22 persons per square kilometer. The capital of the state is El Geneina with 538,390 inhabitants. The eight (8) localities are: Beida, Forbaranga, Geneina, Habila, Jebel Moon and Kerenik, Kulbus, and Sirba [23].

West Darfur has a little over1.8 million inhabitants. It is the third biggest of Darfur's five states with around 12 percent of the population categorized as internally displaced. The majority of the population of the state does not enjoy their full rights and humanitarian and development needs are significant. The major ethnic groups are Aarb, Bargo, Dago, Eringa, Fallata, Fur, Howsaa, Masalit, Mararіet, Misseriya-Jebel, Moon, Tama, Zaghawa [23].

The current study was conducted at El Geneina, Kerenik and Sirba. In Geneina locality the study was done at Rijil Kubri, Jakjakii and Jumaiza villages. In Sirba locality the study was done in Sirba, Banjadeed, and Mororo villagesand Omdukhun and Shotak in El sonta at Kerenik locality, Table2.

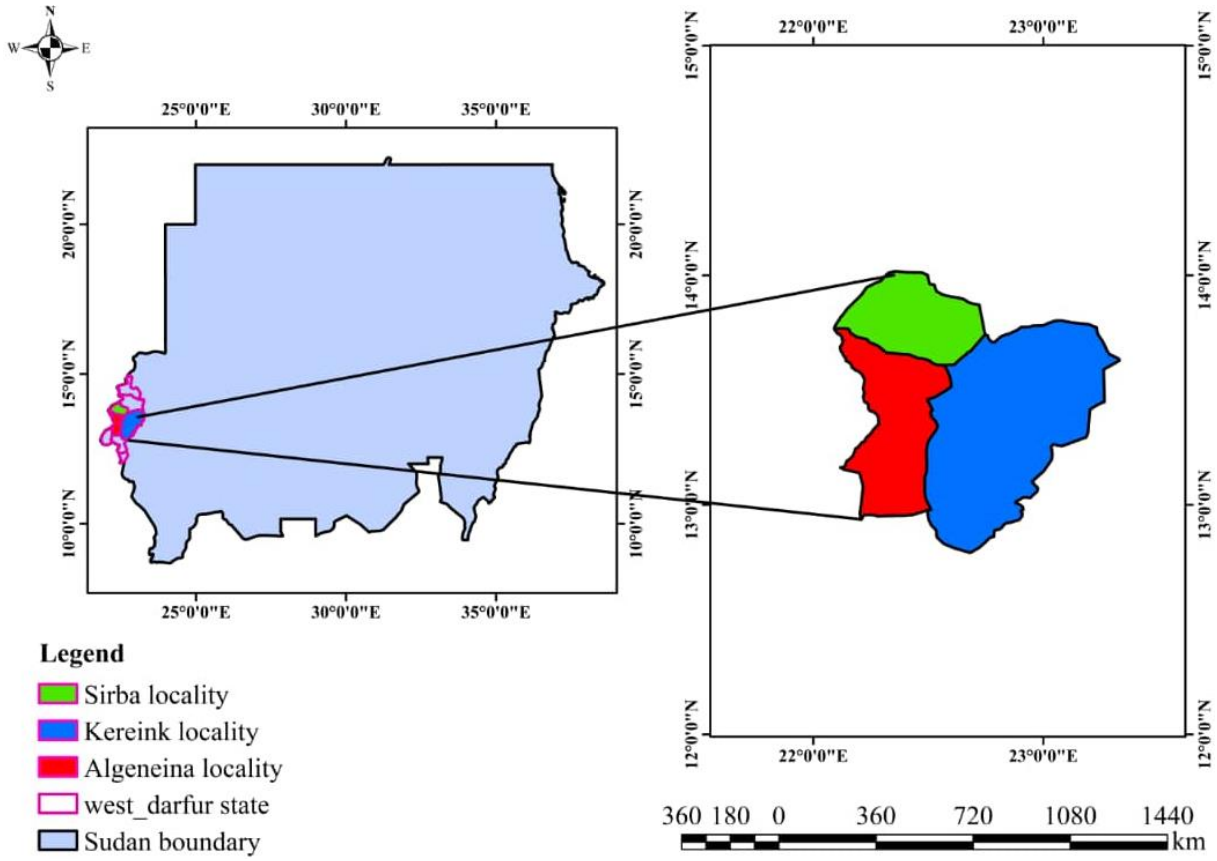

Figure 1. *Location of the Study area.*

Table 1. *The targeted villages in Kerinik, Sirba and ElGeneina localities.*

Locality	Villages	Latitudes	Longitudes
Kreinik,	Kreinik	13.36648	22.8971
	Omdukhun	13.46407	23.01591
	Shotak	13.42210	22.97850
	Sirba	13.80754	22.50385
Sirba	Banjadeed	13.61640	22.26585
	Mororo	13.65331	22.22502

Locality	Villages	Latitudes	Longitudes
El Geneina	Rijil Kubri	13.54488	22.28437
	Jakjakii	13.52215	22.23720
	Jumaiza	13.49970	22.22688

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:

$$VCI = \frac{NDVI - NDVImin}{NDVImax - NDVImin} * 100 (1)$$

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:

$$TCI = \frac{LST - LSTmax}{LSTmax - LSTmin} * 100 (2)$$

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:

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

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

3.6. Field Work

The field work is conducted in the period from 19th of August- 27th August 2019. It is implemented in the targeted localities to accomplish the survey in the targeted 11 villages, covering the selected communities and stakeholders at the state level.

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 vulnerability 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. 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.

Figure 2. *Focus Group Discussion with the targeted communities.*

Figure 3. *Focus Group Discussion with the targeted communities.*

4. Results and Discussion

4.1. Land Use and Land Cover in West Darfur State

The results of land use and land cover in El Geneina locality in WDS are shown in Table 4 and Figure 4. The satellite images showed that 28.9% of the land is grassland, 19.3% is cropland, 30.9% is shrub land and 18.1% is woodland. The vulnerability assessment for the same locality (Table 4 & Figure 7) shows that 87% of the locality areas were classified as non-vulnerable and 13% of the area is classified as slight vulnerable. For Kerinik locality the land use/land cover map (Table 4 & Figure 8) showed that the cultivated land is esti-

mated as 92,108.4 ha which represent about 30.3% from the total area. The grasses and range land is about 101,028.4ha while the shrubs and wood land covers an area of 106.966 ha which represent 35.2% from the total land.However, for Sirba locality the land use/land cover map (Table 4 and Figure 9) shows that 49.6%of the area is grassland, 5.9% crop land, 37.6% of the area is shrub land, 3.1%is woody land and 3.8% is water bodies.

Urban planning, disaster risk assessment, and natural resource management all depend on the timely and accurate production of land use and land cover maps. By examining the spatial distribution and dynamics of LULC classes, these maps aid in well-informed decision-making. Monitoring temporal and spatial changes among LULC classes caused by anthropogenic or natural factors is another important use for LULC mapping. For example, it can monitor the growth of agricultural land, identify the conversion of forests and bare areas to urban areas, and track changes in the area of water bodies [21].

Around the world, remote sensing is utilised to study the venerability of climate change using vegetation indices and LULCC. The NDVI is inversely related to temperature and proportional to precipitation [11]. Over the past three decades, temperature has grown dramatically while precipitation has decreased negligibly. Generally speaking, NDVI values continuously decline from autumn to winter and progressively increase from spring to the rainy season, which is consistent with this study's findings [25].

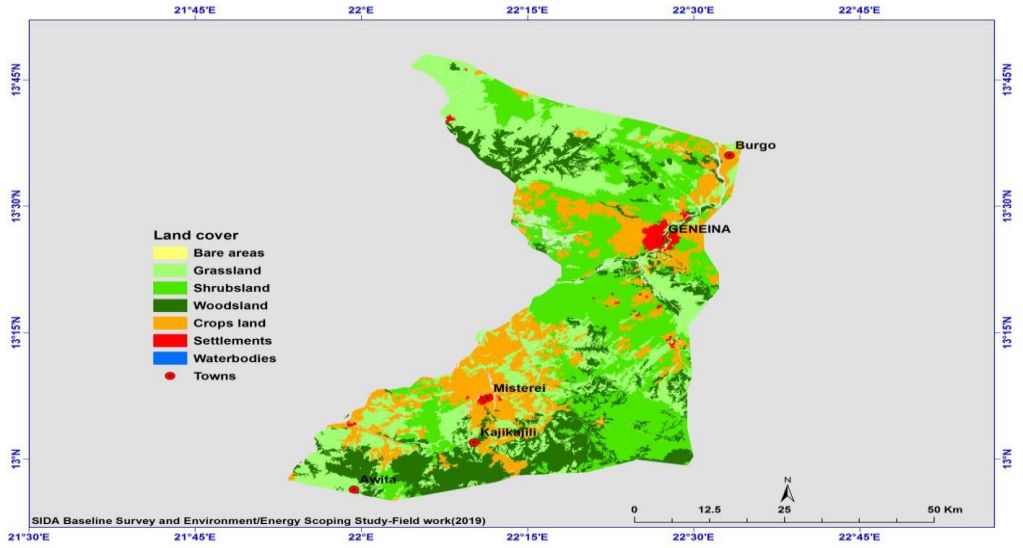

Figure 4. *Land Use/Cover areas of Al Geneina locality.*

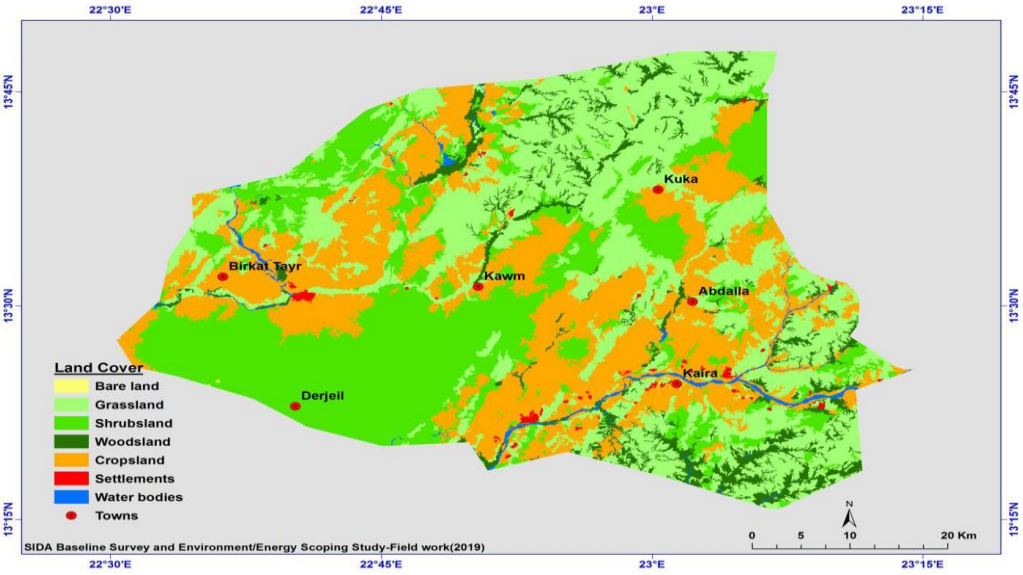

Figure 5. *Land Use/Cover of Kerinik locality.*

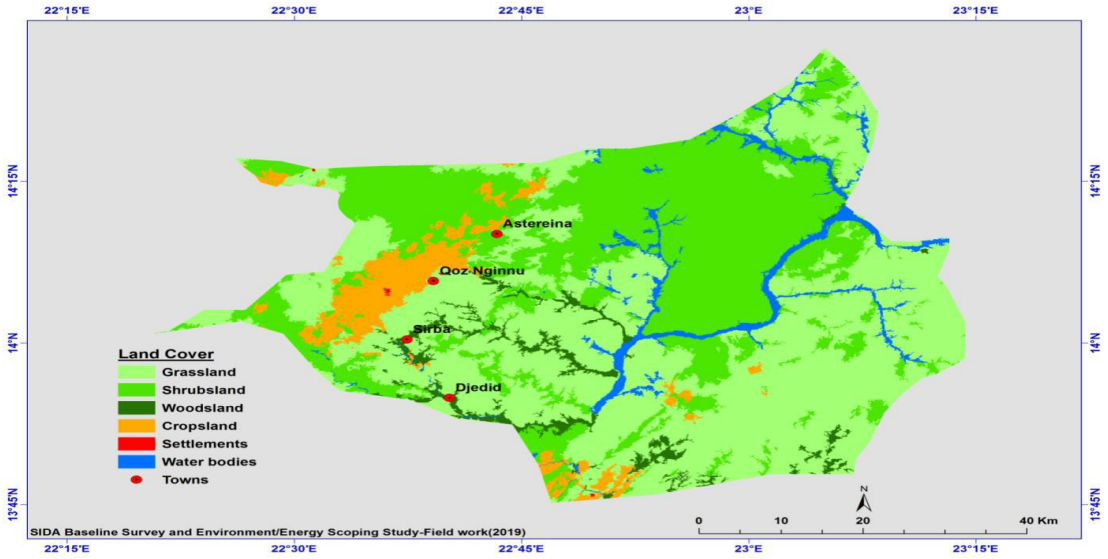

Figure 6. *Land Use/Cover of Sirba locality.*

Table 4. *Land use and land cover in Al Geneina, Kerenik and Sirba localities in West Darfur State.*

Localities	Land use	Area (Ha)	Area (%)
	Bare land	1,344.1	0.4%
	Cropland	67,425.5	19.3%
	Grassland	101,259.8	28.9%
Al Geneina	Settlements	3,800.9	1.1%
	Shrub land	108,272.5	30.9%
	Water bodies	4,410.1	1.3%
	Woodland	63,511.6	18.1%
Total area		350,024.3	
	Bare land	17.5	0.0%
	Crop land	92,108.4	30.3%
	Gras land	101,028.4	33.2%
Kerenik locality	Settlements	1,417.3	0.5%
	Shrub land	88,465.1	29.1%
	Water bodies	2,783.4	0.9%
	Wood land	18,501.1	6.1%
Total area		304,321.1	
	Cropland	23,688.8	5.9%
	Grassland	199,518.8	49.6%
	Settlements	128.3	0.0%
Sirba locality	Shrubs land	150,905.2	37.6%
	Water bodies	15,225.3	3.8%
	Woodland	12,391.6	3.1%
	Cropland	23,688.8	5.9%

Localities	Land use	Area (Ha)	Area (%)
Total area		401,858.0	

4.2. Vulnerability Classification

The study indicated that 87% of the area about 350,024.3 ha from El Geneina locality was classified as non-vulnerable while 45,173.2ha which represent about 13% was classified as slightly vulnerable (Table 5 & Figure 7).

Kerenik locality is classified as non- vulnerable to climate changes. Only 0.5% from the locality area is classified as moderate vulnerable, 13.3% is slightly vulnerable, while 86.2% from the total area is not vulnerable (Table 5&Figure 8).

In Sirba locality about 401,858.0 ha which represent about 87.5% of the locality is classified as non-vulnerable, 12.3% as slightly vulnerable and the 0.2% of locality as moderately vulnerable (Table 5 and Figure 9).

Sudan is one of the driest but also the most variable countries in Africa in terms of rainfall. Extreme years (either good or bad) are more common than average years [29]. Rainfall, on which the overwhelming majority of the country's agricultural activity depends, is erratic and varies significantly from the north to the south of the country. The unreliable nature of the rainfall, together with its concentration into short growing seasons, heightens the vulnerability of Sudan's rainfed agricultural systems.

In Darfur States rainfall has always shown high variability, 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 [19]. 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. Only the high rainfall savannas of the southern area are less vulnerable to drought. Without appropriate planning, future climate change is expected to have serious impacts on Darfur's economy and population. For example, shifting rainfall patterns and high demand are rapidly depleting groundwater levels [17]. Official reports show an alarming decline in water levels around El Fasher and propose that, if rainfall variability continues, crop failures will increase to 70% by 2050 [24].

The ecological systems often have "multiple domains of attraction," separated by thresholds beyond which they can shift into completely different regimes [12]. In this case, recurring droughts combined with land misuse, such as overgrazing and deforestation; threaten to push local agro-pastoral areas into a degraded, desertified condition that is extremely difficult to reverse. The resilience depends on the ability to persist and adapt, whether the changes are expected or sudden, across different pathways and threshold points [5, 9].

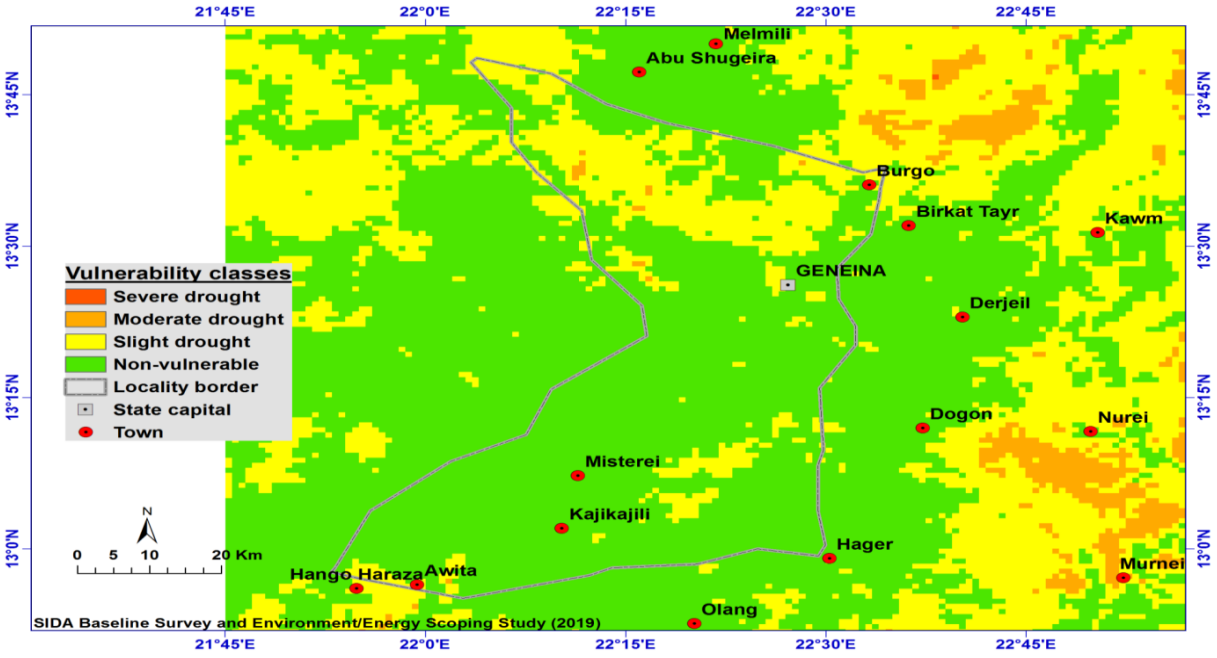

Figure 7. Climate Change Vulnerability at Geneina locality.

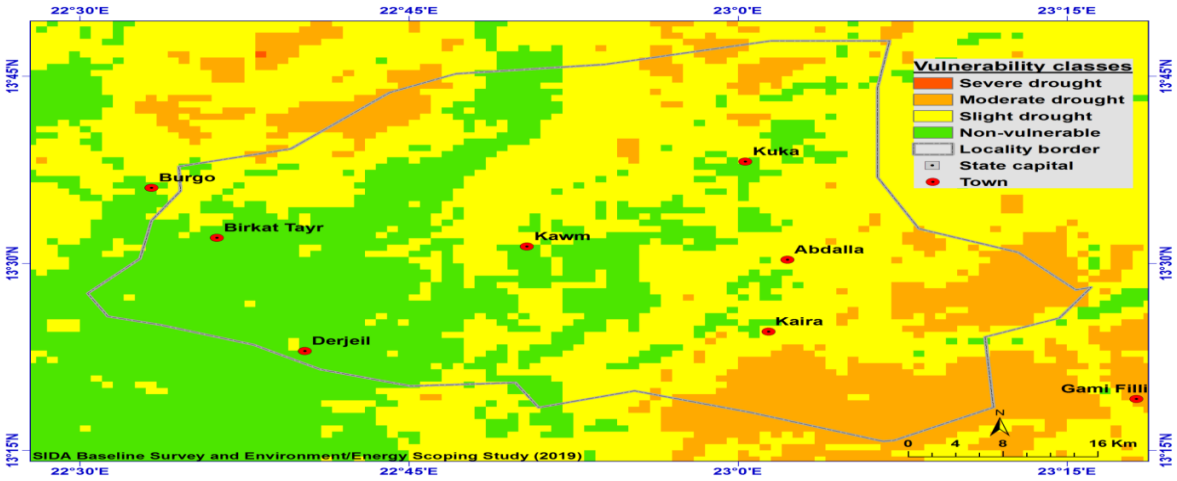

Figure 8. *Climate change Vulnerability at Kerinik locality.*

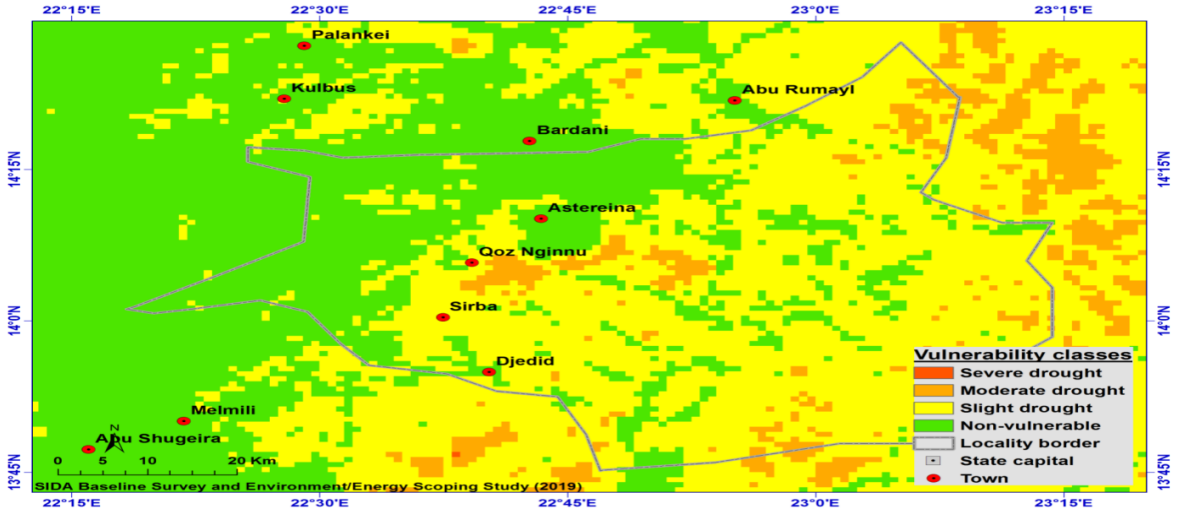

Figure 9. *Climate change Vulnerability at Sirba locality.*

Table 5. *Vulnerability classes at the targeted localities.*

Localities	Vulnerability classes	Area (Ha)	Area (%)
Geneina	High vulnerable	-	0
	Moderate vulnerable	24.4	0.01%
	Slight vulnerable	45,173.2	12.9%
	Non-vulnerable	350,024.3	87%
Kereinik	High vulnerable	-	
	Moderate vulnerable	1,569.1	0.5%
	Slight vulnerable	40,538.8	13.3%
	Non-vulnerable	304,321.1	86.2%
Sirba	High vulnerable	-	0.0%
	Moderate vulnerable	624.6	0.2%
	Slight vulnerable	49,426.8	12.3%

Localities	Vulnerability classes	Area (Ha)	Area (%)
	Non-vulnerable	401,858.0	87.5%

4.3. Impact of Climate Vulnerability in Crop Production at the Targeted Localities

The main field crops in the targeted localities are millet, sorghum, groundnut, and sesame, Roselle, maize, and watermelon, vegetables crops such as tomato, onion, potato, snick cucumber, okra and fruits Mango, Guafa and Banana.

The main factors that affected crop productivities in the targeted localities include; Low soil fertility, outbreak of best and disease, lack of improved crop varieties', crops damage by animals, lack of finance credits, rainfall shortage, poor transportation, low crop prices and poor extension services.

Crop productivity in the targeted localities was decreased due to the above mentioned factors and the production is not sufficient for household consumption. The farmers compensate the yield losses through collection and selling fire wood and charcoal, work as casual labor in garden, selling of small animals and crop residues, migration to big cities.

No improve seeds or cultural practices were reported in Geneina locality. Some of improved crop varieties were found such as millet (Ashana), groundnuts (Sodari), Sorghum (Wad Ahmed and Butana) were found at Kerinik and Sirba localities.

The adaptation methods that suggested by the local communities are provision of improved seeds, pesticides and fertilizers, provision and application of mico-doze fertilizers, mechanization, intermediate technologies, strengthen of extension services and protection of farms from animal damage.

Sudan's major environmental problems are deforestation, overgrazing, soil erosion, and desertification. In arid zones, historic vulnerability to drought has combined with anthropogenic pressures to create a situation of declining soil fertility and water resources, low agricultural productivity, and persistent food insecurity [17]. The conflict that broke out in April 2023 occurred towards the end of the 2022/2023 winter harvest season. Subsequent 2023 summer season planting activities were disrupted as was access to pasture and water for livestock rearing households. Labor availability plummeted looting and destruction of already available food and seed stocks increased, as well as escalated prices of farm inputs [8, 13]. The war has hindered not only the winter planting activities but also the repair of irrigation infrastructure [4, 15].

Several vulnerability indices rank Sudan among the most vulnerable countries in the world to climate variability and change. Many parts of Sudan, including Darfur, have increased frequency of droughts, desertification, and high rainfall variability over the past few decades, which contribute to the deteriorating socio-economic situation of communities and households. Desertification has been a significant stress factor in pastoralist societies and contributed to inter-communal tensions. Besides, a cute, and chronic food insecurity continues to threaten people's lives and livelihoods and is driven by prolonged conflict, environmental deterioration, and disasters. As long ago as 2007, research carried-out by the UN Environment Programme found that - with rainfall down by up to 30 per cent over 40 years and the Sahara advancing by well over a mile every year - tensions in the Sahel and specifically Darfur were increasing between farmers and herders over disappearing pasture and evaporating water holes.

A remote sensing assessment conducted by the Food and Agriculture Organization of the United Nations (FAO) during the 2023 summer season indicated an 82 percent reduction in irrigated cultivated areas in July, followed by decreases of 9 percent in August and 4 percent in September. Additionally, the rainfed cultivated area decreased by 48 percent in July, 7 percent in August and 9 percent compared to the five-year average [4, 15].

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

No reserved or unreserved forest was reported in Geneina locality in this study. The trees is found scatter around the cultivated land and the settlement areas. The main tree species in the targeted villages are *Clotrpis procera* " Osher", *Blanites aegyptiaca* "Heglig), *Boscia senegalensis* "Kursan", *Acacia mellifera* (Kiter), *Acacia seyal* (Talh), and *Combretum cordofanum*(Habil). In Kereinik locality the main tree species include *Clotrpis procera* "Oshar", *Balanites aegyptiaca* "Heglig", *Boscia senegalensis* "Kursan", and *Acacia mellifera* (Ketir). The important tree species at Sirba locality were *Boscia senegalensis* "Kursan, *Acacia mellifera* "Kitir", *Acacia seyal* "Talih", *Combretum cordofanum* "Habil, *Acacia senegal* "Hashab", Albizia amara "Arad", Faidherbia albida "Haraz", *Ziziphus spina- christia* "Sidir", *Tamarindus indica*" Ardeib", *Anogeissus leiocarpus* " Sahab", Acaia nilotica "Sunt", *Ficus glumosa* "Gumaiz". The result showed that the forest biomass (Firewood+ charcoal) is the main source of energy and the majority of the local communities (more than 90%) depend on the firewood as source of energy for cooking and lighting. Furthermore, the majority of populations around the forest area have access to collect the dead wood. No using of improved stove was reported in the targeted village. Usually the fire wood collected by women girls and boys, they walk more than 10 hour searching for woods. For building

materials the communities collect them from forest and buying them at the local market.

The main factors that lead to forest deterioration in the targeted area include (1) Illicit cutting, (2) Increasing in human and animal population (3) rainfall fluctuation, (4) animal grazing and (5) expansion of agriculture into the forest and range land.

The suitable intervention in the forestry sector for the targeted villages include (1) Enforcement of forest law, (2) Establishment of village nurseries and community forestry, (3) Establishment of shelter belts and wind breaks (4) Provision of improved stoves and solar energy (5) Using of solar energy and improve stove (6) Provision of the LPG.

Crops and forestry are the most vulnerable subsectors to climate change impacts. The impact of climate change on the forestry sector include; frequent and more intense wildfires, habitat losses, changes in the incidence of pests and diseases, including new outbreaks, poor regeneration of species, unpredictable rainfall pattern, genetic diversity of species and increased pressure on forest resources (human migration and settlements) [7].

Despite its vast land area, the largest in Sub-Saharan Africa, and relatively low overall population density, sustainable development in Sudan remains a significant challenge from both an environmental and socio-economic perspective. The unavoidable reality is that the existing natural environment status with all its components is in steady decline. There are many key driving forces of the continued environmental degradation which could possibly be curtailed by translating the theoretical intent into a practical strategic planning approach but there are also avenues and opportunities to remedy the situation [10].

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 represent major factors among others that lead to forest degradation [28]. The direct dependence of Sudanese communities on the natural environment for survival has contributed to competition and conflict over scare natural resources. Indeed, most of the past conflicts have been resource-based in nature, often between pastoralists and farmers. The prospect of climate change increases the urgency to find creative ways of bringing communities together in a spirit of adaptation, to share finite resources and encourage a collective responsibility towards sustainable management of local resources [17].

4.5. Impact of Climate Vulnerability in Range Land Condition at the Targeted Localities

The results showed that the majority of the communities in the targeted localities have an idea about climate change. The area was affected by hot weather, dust storm and flooding. The range grasses are not sufficient to feed the animals especially during the dry season. The pastoralist in the dry season use crop residues, straw, green forage (*Medicago sativa*) and concentrates to feed their animals, the palatable species in the El Geneina locality were decreased. These species are *Dactyloctenium aegyptium* (Abuasbi), *Zornia glochidiata* (Sheilimi). In contrast, the results showed that the unpalatable species were increased compared with the past periods. The invader range species include, *Cassia spp (Kawal, Sorieb), Amaranthus sp (lissan Eltair), Stereospermum kunthianum (Khirwii), Datura sp (Sikaran), Abutilon angulatum (Nada), Acanthospermum hespidum, (Hurab hawsa), Zanphium sp (Ramtouk), Ladob* (un known). The main sources for animal grazing during the rainy season is the natural pasture land (Figure 10) while during the dry season the farmers and herders depends on crop residues, straw, green forage (*Medicago sativa*) and concentrates (Millet sorghum grains, cakes) for animal feeding.

The factors that lead to deterioration in condition in the targeted localities include; water shortage and un equal distribution of water point, over stocking and grazing, fire outbreak, expansion of cultivated land, increase in human and animal population, decreasing of palatable species and fodder trees, animal disease and lack of vaccination and, the disputes between farmers and pastoralists.

The results from (KII) interview in the targeted localities showed that many NGOs have been worked in the field of natural resources management. These organizations include CRS, WFP, CONCERN, WR, UNDP and DRA. The intervention that made is range seed broadcasting, establishment of nurseries, establishment of farmer's field schools. The suitable intervention from range and pasture department point of view include; rising awareness between farmers and pastoralist, participation of local communities and stakeholders in planning and implementing therange rehabilitation activities, planting and protecting of fodder trees, improvement of veterinary services, and capacity building in range improvement and management.

This result are in agree with the finding of [3] who stated that "rangeland in Darfur were seriously degraded, the reasons behind rangeland degradation were the high level of insecurity, over-grazing and seasonal fires which represent the main causes of rangeland degradation, in addition to loss of management and desirable grasses, or maybe referred to highly concentration of grazing in the forest and this make pressure on the forest lands".

With deterioration of rangeland, pasture-land and disappearing of the most palatable species from the pasture areas and with limited/and or absence of any improvement inter-

ventions, pastoralists were completely depend on the range resource as main food resource for the large number of animal wealth, this overgrazing activities were greatly affected the growth and regeneration of some palatable range species. Moreover; the increasing process of overgrazing were contributed to the current situation of degradation in the region [27].

Figure 10. *Range and pasture land at Kerenik locality.*

4.6. Climatic and Non-climatic Events in the Targeted Localities in West 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 [6]. 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 area experiences successive drought years the area experiences successive drought years in 1983, 1984, 1985, 1986,202 and 2018 beside the war in 2003 and 2023. the consequences of all this factors include; shortage of water, shortage of foods, dust storms, bush fires, crop failure, dead of trees, loss of livestock, food gap and famine and death of children and elder people Table 6.

In response to the challenges of climate change, households adopted the following coping strategies: migration selling assets borrowing money reduced food consumption and requesting social support. Violence and displacement are disrupting agricultural activities, reducing domestic food supply, and raising prices, while increasing vulnerability to further shocks, including those induced by climate change.

Table 6. *Climatic events in Geneina Locality south Darfur Sate.*

Years	Events	Impact	Consequences	Coping strategy
1983	No rainfall	drought	dust storm, bush fires, low crop yield deterioration of rangeland, starvation, death of both people and animals, soil erosion, malnutrition, strife, migration and desertification.	Migration of people to bigger town's use of *tree fruits and* seeds as source of food. Selling assets
1984	No rainfall	drought	storm, bush fires, crops failure deterioration of rangeland, starvation, death of both people and animals, soil erosion, malnutrition, strife, migration and desertification	Migration of people to bigger towns use of famine foods
1985	No rainfall	drought	dust storm, bush fires, Soil erosion, low crops yield, deterioration of rangeland,, malnutrition, starvation, death of both people and animals	Migration of people to bigger town's use of trees and plants seeds.
1986	High rainfall	flood	Deterioration of rangelands, gulley erosion, Decrease Crops production	Migration of people to bigger towns.
2018	High rainfall	Flood	Reduction in crop production Food gab. death of some animals	migration, borrowing money, selling assets
2002	High rainfall	flood	Reduction of both crops and vegetables production, Food gab Death of some animals.	reduced food consumption, requesting social support

5. Conclusion and Recommendation

The food security situation in West Darfur State is the result of a complex interplay of factors that the ongoing conflict has exacerbated. Most people in West Darfur particularly in the rural areas depend on agriculture and crop production as a source of living and on forests to obtain energy for different purposes such as cooking, lighting, manufacturing of red bricks and also to obtain building poles for construction, this practice led to environmental degradation, therefore the study recommend to use improved seeds, pesticides and fertilizers, mechanization, intermediate technologies, strengthen of agricultural and extension services to improve the food security in the targeted localities. For forestry sector the recommendation include; establishment of village nurseries and community forestry, establishment of shelter belts and wind breaks, provision of improved stoves and solar energy. The recommendations for improvement of range condition in WDS include adoption of water harvesting techniques; equal distribution of the water point, rehabilitating of range land by reseedings of perennials palatable range species, medicines and vaccines, opening of the fire lines to protect the range land from wildfire and range improvement by broadcasting of seeds to enrich the soil seeds banks.

Abbreviations

AI	Aridity Index
FGD	Focus Group Discussion
IDP	Internally Displaced People
KII	Key Informants Interview
LST	Land Surface Temperature
LULC	Land Use and Land Cover
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NRM	Natural Resources Management
TCI	Temperature Condition Index
VCI	Vegetation Condition Index
VHI	Vegetation Health Index

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Abusuwar, A. O., & Daffalla, H. (2016). The role of traditional rainwater harvesting techniques in combating desertification in dry areas of Sudan. *International Soil and Water Conservation Research*, *4*(1), 43-50.

[2] Adam. H. S (2008). Agro climatology, Crop Water Requirement and Water Management. Gezira Printing and Publication Co. Ltd. Wad Medani. Sudan.

[3] Alaaeldein, A. Yousif, Talaat, D. Abdel Magid, Ahmed. Y, Ibrahim (2021). Impacts of Darfur War in Degradation of Natural Forest, IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS) e-ISSN: 2319-2380, p-ISSN: 2319-2372. Volume 11, Issue 3 Ver. III (March 2018), PP 47-54. www.iosrjournals.org

[4] Barhy, A., Mukaratirwa, R., Jalal, R., Farren, F., Ghosh, A. Mohamed, A., AbdAllaElshekh, M., Adam, A., Warrag, A., Warrag, E., Ali, I., Igbokwe, K., Yao, A. and Henry, M. 2024. Geospatial cropland monitoring and crop type mapping of the Gezira irrigation scheme in the Sudan - 2019/20-2023/24 (September to March). Rome, FAO. https://doi.org/10.4060/cd1386en

[5] Chen, X., et al. (2020). *Spatial-temporal variations of NDVI and its response to climate in China from 2001 to 2020*. Journal of Geographical Sciences, 32(9), 1547-1567.

[6] FAO (2020). The state of food security and nutrition in the world 2020. Transforming food systems for affordable healthy diets. Food and Agriculture Organization.

[7] FAO (2021). Consultative Meeting for the Southern and Eastern Africa Sub-Regions on the African Union Climate Change Strategy, 28-30 July 2021.

[8] FAO. 2024a. *Sudan: Assessment on the impact of floods - DIEM-Impact report, October 2024*. Rome. https://doi.org/10.4060/cd2924en

[9] Folke, C. (2016). Resilience (Republished). *Ecology and Society*, *21*(4), 44.

[10] Gafaar, Abdalla (2011). Forest Plantation and woodlots in Sudan. African forest forum working paper series. www.afforum.org.

[11] Ghebrezgabher, M. G., et al. (2020). Assessment of NDVI variations in responses to climate change in the Horn of Africa. *The Egyptian Journal of Remote Sensing and Space Sciences*, *23*(3), 333-343.

[12] Holling, C. S. (1973). Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics*, *4*, 1-23.

[13] IPC (Integrated Food Security Phase Classification). 2023. Sudan: Acute food insecurity situation June 2023 and projections for July−September 2023 and October 2023−February 2024. In *IPC*. Rome. [Cited 4 November 2024]. https://www.ipcinfo.org/ipc-country-analysis/details-map/en/c/1156504/?iso3=SDN

[14] Kinda, S. R., & Badolo, F. (2019). Does rainfall variability matter for food security in developing countries? Cogent Economics & Finance, *7*(1): 1640098 https://doi.org/10.1080/23322039.2019.1640098

[15] Kumar, V., Jalal, R., MukhtarHamid, E., Gareeb Alla Abd Alla, M., Warrag, E., AbdAlla, A., Perri, P.T., Mukaratirwa, R., Ghosh, A. & Henry, M. 2023. Geospatial assessment of cultivated cropland extent in the Sudan - July to September 2023. Technical report. Rome, FAO. https://doi.org/10.4060/cc8795en

[16] Mohmmed, A.; Zhang, K.; Kabenge, M.; Keesstra, S.; Cerdà, A.; Reuben, M.; Elbashier, M. M.; Dalson, T. & Ali, A. A. (2018). Analysis of drought and vulnerability in the North Darfur region of Sudan. Land Degradation & Development, 29(12): 4424-4438. https://doi.org/10.1002/ldr.3180

[17] NAPA, 2016. National Adaptation Plan. Republic of the Sudan, Ministry of Environment and Physical Development, Higher Council for Environment and Natural Resources, Khartoum.

[18] NAPA. 2007. National Adaptation programme of Action. Republic of the Sudan, Ministry of Environment and Physical Development, Higher Council for Environment and Natural Resources, Khartoum.

[19] North Darfur State NAP Committee, 2013. North Darfur State NAP Report on Assessment of Climate Change Vulnerability and Adaptation Options and Strategies

[20] Pickson, R.B. & Boateng, E. (2022). Climate change: A friend or foe to food security in Africa? Environment, Development and Sustainability, 24(3):4387-4412 https://doi.org/10.1007/s10668-021-01621

[21] Sultan, M., Issa, S., Dahy, B., Saleous, N., & Sami, M. (2024). Fifty years of land use and land cover mapping in the United Arab Emirates: A machine learning approach using Landsat satellite data. *Frontiers in Earth Science*, *12*, 1510510. https://doi.org/10.3389/feart.2024.1510510

[22] Ujunwa, A., Okoyeuzu, C., & Kalu, E. U. (2019). Armed conflict and food security in West Africa: Socioeconomic perspective. International Journal of Social Economics, 46(2): 182-198. https://doi. org/10.1108/IJSE-11-2017-0538

[23] UNCEF, 2022. State Profile, West Darfur.

[24] UNEP (2007), *Sudan - Post-Conflict Environmental Assessment*. Nairobi: United Nations.

[25] Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society, 9*(2), 5.

[26] West Darfur State NAP Committee, 2013. West Darfur State NAP Report on Assessment of Climate Change Vulnerability and Adaptation Options and Strategies.

[27] Yousif, A. Abdelrahman (2017). Ecological and Social impacts of Darfur war. A case Study Thur Natural Forest - Jabel Marra Central Darfur State - Sudan. M. S.c Thesis, College of Natural Resource and Environmental Studies.

[28] Yousif, A. Abdelrahman. (2023). Forest Crises in Darfur decreasing Afforestation.: https://www.researchgate.net/publication/374910393

[29] Zakieldeen, SA. 2007. Vulnerability in Sudan. tiempo bulletin 62. Online bulletin at: www.tiempocyberclimate.org