

Research Article

Effect of Climate Change Vulnerability on Agriculture, Forestry and Rangel Land Condition in White Nile State, Sudan (A Case Study of El Slam and El Dweim Localities)

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Abstract

This study was carried out during 2019 in El Slam and El Dweim localities White Nile State (WNS), Sudan with aim to investigate the impact of climate change vulnerability on crop production, forestry and range land in WNS. Three methods for data collection were used (1) Vulnerability assessment by using the satellite images (2) Key informant interview (KII), and (3) Focus group Discussion (FGD). The results showed that the main field crops in the two localities are sorghum, sesame, mellit, groundnut and watermelon and vegetable crops. Crop production was highly affected by climatic and non-climatic factors which include; low and erratic rainfall, outbreak of pest and diseases (striga), lack of improve seeds, lack of proper storage capacity, flooding especially, mono-cropping which lead to soil deterioration and striga infestation, lack of financial support and poor extension services. The remote sensing data from 2000-2018, showed that the forest cover in El Salam locality was decreased from 365,726 ha in 2000 to 147,089 ha in 2018 about 250,282 ha of the forest land were converted to non-forest land including 41% to agricultural land and 26% to grazing land. In contrast in El Dweim locality the results showed slight improvement in forest cover. The range condition in the two localities was deteriorated compared with the past periods. In Elsalam locality the range land was estimated at 264,702 ha in 2000, by year 2018 almost 85% of these areas were converted to non-grassland as follows:(75%) to agriculture land and (10%) to urban areas. In El Dweim locality the decrease is about 52%. Generally, the deterioration of the range land can be attributed to many factors such as low and erratic rainfall, fodder shortage, poor distribution of water point, fire outbreak and speared of invader species. The study recommended many intervention to improve agriculture production such as the dissemination of improved seeds (drought resistant and early maturing); promotion of vegetable production to improve nutrition. For both forest and rangeland condition which include; planting of 10% of the area of the agricultural land with forest trees; establishment of shelterbelts and promotion of social forestry; and enforcement of natural resources legislation, provision of improved stove and LPG, introduction of agroforestry systems, establishment of community forestry, provision of tree seedlings, rehabilitation of degraded range land, opening of fire lines and provide new water.

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Keywords

Climate Change, Sudan, Agriculture, Forestry, El Duwaym Localities

1. Introduction

The IPCC Third Assessment Report (TAR) describes vulnerability as “The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity [3]. This is already evidenced by a significant decline in tree density and desertification. These climate trends and risks are predicted to be exacerbated by a number of non-climate issues such as: decreased vegetation cover due to overgrazing and deforestation, and inefficient management of water resources [3].

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 [9, 13].

Vulnerability is the potential to be adversely affected by an event or a change and the ability to cope with or recover from its impacts. The extent to which climate change may damage or harm a system depends on the system’s sensitivity and ability to adapt to new conditions. Physical vulnerability refers to exposure to stress and crises resulting from physical hazards, while social vulnerability refers to the inability of individuals and communities to respond to physical impacts. Vulnerability may be considered at many levels, including the individual, household, national or regional level. Adaptation is the adjustment in natural or human systems in response to actual or expected climatic change or their effects, to reduce harm or exploit beneficial opportunities. Adaptation involves changing processes, practices or structures, either automatic or planned, by individuals, households, governments and other stakeholders. The capacity to adapt depends largely on access to assets (including natural resources; and human, technological, social, physical and financial capital) and how well these are used [10].

White Nile State is vulnerable to climate change and the situation in WNS has adversely impacted water availability and agricultural potential, through increased frequency of droughts, dust storms and heat waves [8]. There is also an increasing frequency of extreme flooding events caused by an increase in intensity of rainfall both during the rainy season

and in rainstorms. These climate trends and risks are exacerbated by a number of non-climate issues such as: decreased vegetation cover due to overgrazing and deforestation, and inefficient management of water resources – thus further increasing trends of ecological zone shift and desertification. Almost all localities in the western side of White Nile River were found to be among the most vulnerable to droughts and other impacts of climate change. These impacts have already been manifested in declining crop productivity, loss of grazing resources and rangeland valuable species, land degradation, increased frequency of diseases crops, livestock and population, loss of livelihoods and human migration in search for jobs and alternative livelihoods [8]. While climate impacts are severe across the state, the communities on the western bank of the White Nile River are particularly vulnerable due to several factors. These include: low general awareness of climate change; lack of knowledge about water harvesting; lack of access to improved seeds and other agriculture inputs; presence of overgrazing and severe deforestation; high poverty levels and lack of alternative livelihood systems; lack of technology and know-how for better agricultural practices; and high frequency of rangeland fires [8].

The increase in global temperature will affect all the Sudan. Vulnerable sectors to rises in temperature are particularly rainfed agriculture, aquaculture, natural ecology systems and biodiversity, water resources, and energy (production and consumption). This ultimately increases the vulnerability of certain communities, such as poor farmers, pastoralists and generally communities that rely on rainfed agriculture. But the Sudan will not only experience changes in mean temperature, which are projected to increase by up to 3°C by 2050, and precipitation, which is projected to increase by 4 percent per decade, but also increasing rainfall variability with increased frequency of both droughts and floods [17]. Floods, flashfloods, and possibly landslides affect the southern and southeastern parts of the country as well as the mountainous areas in the northeast, while droughts affect more the northern parts and areas in the middle and Middle West of the country. Communities that are most vulnerable to droughts and floods are pastoralists, poor farmers, and generally poor families with senior members, children, and women [12].

One of Sudan’s most vulnerable regions that are severely impacted by climate change induced hazards (droughts and floods) is the White Nile State (WNS) especially the western region of the state. As indicated in Sudan’s National Adaptation Program of Action [9] and National Adaptation Plan

(NAP-2016), small holder rain-fed farmers and pastoralists in the White Nile State are particularly vulnerable to climate change due to inappropriate and unsustainable agricultural practices, insufficient water and land management and lack of alternative non-agricultural and non-pastoral income generating activities [8]. Most notably, increasing temperatures, decreasing trends of annual precipitation as well as increased variability, are causing a gradual shift of arid ecological zones from north to south. As a result, climate change impacts in WNS have already been manifested in declining crop and animal productivity, loss of grazing resources and rangeland valuable species, land degradation, increased frequency of human, animal and crop diseases, loss of livelihoods and human migration in search for jobs and alternative livelihoods [8].

Under the current and predicted effects of climate change including increases in the frequency and severity of drought events it is likely that the poor living conditions of rural communities will be further exacerbated. For example, increased frequency and intensity of drought events are likely to affect agricultural yields negatively, thereby compounding food insecurity in the rural region [9].

In the White Nile State in particular, almost 70% of the 1.7 million inhabitants live in the rural areas and are dependent on

traditional rain-fed agriculture and livestock rearing for their livelihoods. The White Nile State's animal resources are estimated at 7.9 million heads [16].

The overall objectives of this study is to provide information and recommendations to plan and implement genuine interventions to better management of natural resources and introduce appropriate technologies to help reduce dependency on wood, grass and other natural resources as sources of energy and building materials.

2. Material and Methods

The study was conducted in two localities in White Nile state, ten villages in El Slam locality namely (Alrawat, Mejikha, Aburakhia, Wad Alkut, Abudabaka, Alsuwalik, Almarabie, Nafal and DuraaAlwaheed) and three villages in El Dweim locality (Wad Gabur, Elhelba and AgaidatEl Tair villages) Table 1. In addition to Key informant interview (KII) with State Ministry of Agriculture (MoA), Forestry National Corporation (FNC), Range and Pasture Administration, non-state actors, and NGOs at White Nile State levels.

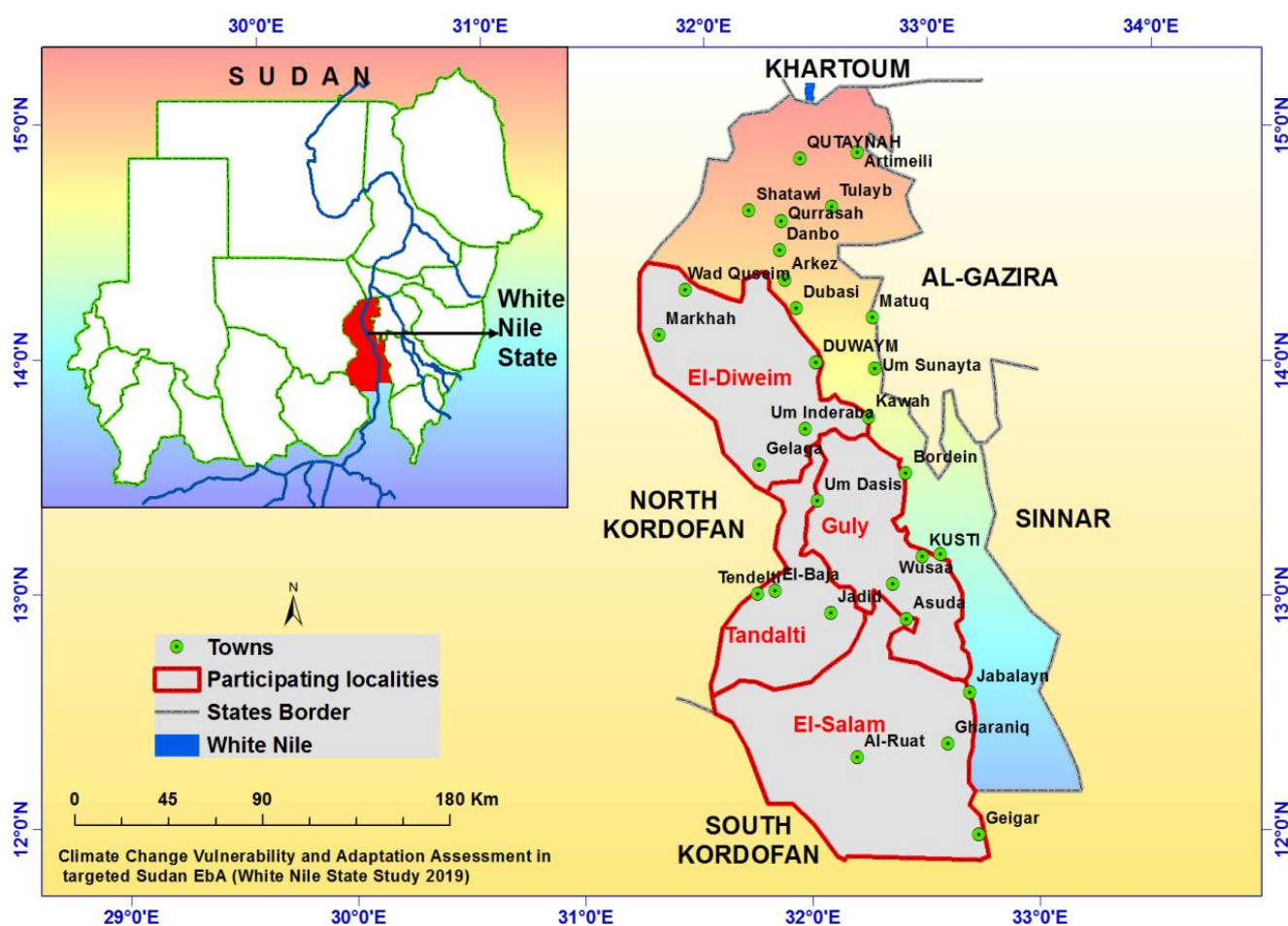


Figure 1. Targeted Localities.

Table 1. Description of some of the Targeted Villages, Main Features and Administrative Setup.

Village	Locality	Admin. unit	Description	Administrative bodies
Mejikha	Alsalam	El Rawat	Surrounded by agricultural area, the houses are made of mud and rarely breaks	2 sheikhs, One vice, Popular committee
Alrawat	Alsalam	El Rawat	Surrounded by more than 4000 feddan of arable soils. The houses are made of red breaks and mud	One sheikh, One vice, Popular committee
Duraa Al-waheed	Alsalam	El Rawat	The buildings composed of mud and straw and the whole village is surrounded by the agricultural lands	One sheikh, One vice, Popular committee
Alsuwalik	Alsalam	El Rawat	The houses are made of palm leaves, straw, wood and mud. they used to be nomads and they recently settled in 2009	One sheikh, One vice, Popular committee
Wad Alkut	Alsalam	El Rawat	The houses are built from mud and most of it with no fences.	One sheikh, One vice, Popular committee
Elhelba	El Dweim	Shabasha	The houses are build form mud, red breaks and cement blocks and the land is sandy soil.	One sheikh, One vice, Popular committee
Agaidat El Tair	El Dweim	Shabasha	The whole area is sand soil, the houses are huts build from mud, wood and straw with very few made from red breaks (Durdur)	One sheikh, One vice, Popular committee)
Wad Gabur	El Dweim	Shabasha	Sandy soil with buildings made of mud and red breaks.	One sheikh, One vice, Popular committee

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

3.6. Field Work

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 coping 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. Rainfall Distribution in the Study Area

Figures 2 & 3 shows the variability in rainfall in Kosti and El Dweim localities in WNS during the period 1881-2018. Average annual rainfall is 348 mm/yr in the Northern areas 300mm/yr and 600 mm/yr in the Southern areas. The average maximum temperature of 37°C during the summer season and average minimum temperature of 22°C during the winter season. The rainfall is erratic and show uneven distribution from year to year and from place to place. The erratic and uneven distribution of the rainfall leads to a series of improper adaptive coping strategies. 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 [20]. 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.

According to NPA, 2016 almost 70% earn a living based on traditional rainfed agriculture and livestock. The White Nile State is severely impacted by the climate change induced droughts and floods. Most notably, increasing temperatures, decreasing trends of annual precipitation as well as increased

variability, are causing a gradual shift of climate and ecological zones from north to south. That is, formerly semiarid ecological zones, such as the majority of the White Nile State, are gradually moving southward as the climate becomes increasingly hotter, thus taking on characteristics similar to the arid zones currently found further north [8].

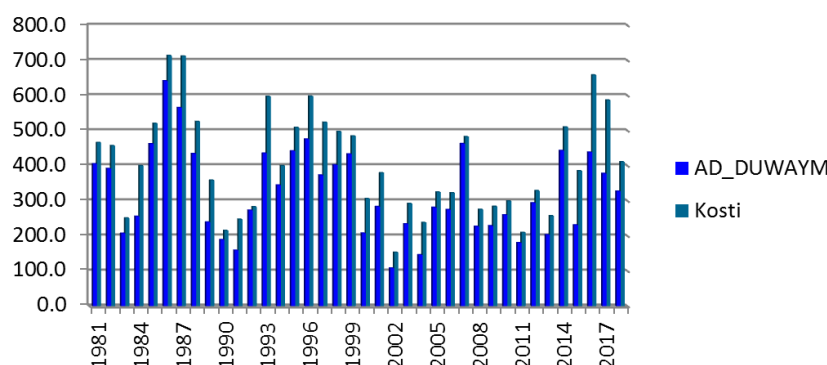


Figure 2. Average Rainfall in Kosti and Ad Dweim Localities from 1981-2018 Source (SMA).

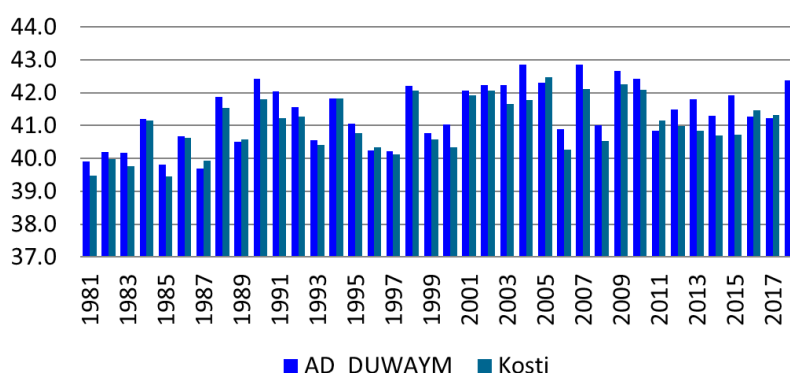


Figure 3. Average Maximum Temperature in Kosti and Al Dweim Localities from 1981-2018.

4.2. Land Use and Land Cover (LULC) at the Targeted Localities

Al Salam locality accommodates the highest number of South Sudanese refugees in WNS. The locality lies along the western bank of White Nile River from El Rideis village up to Kilo 10 in further southern part of the locality. The results showed that the cultivated land in Al Salam locality occupies 44.8% of the area, followed by grassland and shrubs-land which represent 43.4% from the total area while the forest cover represents only 10.8% of the locality area (Table 4). As illustrated in, rain-fed cultivation is practiced in the west-south side of the locality, which bordering South Kordofan State, whereas rangeland is confined in the eastern and western site of the locality (Figure 4).

According to the land use and land Sat (LULC) map for El Dweim locality, the agriculture land covers about 318,760 ha which represent 51% from the locality area, forest land 70,777

ha which represent 11.3%, grass land 72,462.8 ha which represent 11.6% from the total area, shrubs 148,268.1 ha which represent 23.7% while the water bodies, settlements and bare lands were represented by 1.1, 1.1 and 1% of each one respectively (Table 3, Figure 3).

The land cover atlas of the Sudan [5] classifies the total land area of the country (188 million hectares) into 83 different classes that are aggregated into seven major classes. Agriculture is mainly practiced on land in the 'agriculture in terrestrial and aquatic/regularly flooded land' category, which makes up 23.7 million hectares and represents 12.6 percent of the country's land area. A brief look at the distribution of this land cover class across states shows that the majority is found within the predominantly rainfed states of northern Kordofan (19.3 percent), El Gadarif (14.6 percent), southern Darfur (9 percent), White Nile (8.7), and southern Kordofan (8.3 percent).

Around the world, remote sensing is utilised to study the vulnerability of climate change using vegetation indices and

LULCC. The NDVI is inversely related to temperature and proportional to precipitation [6]. 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 [18].

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 [14].

Table 4. Areas of Land Use and Land Cover (LULC) Classes in the Targeted Localities.

Land use classes	Area (Ha)	Area (%)
Agriculture	421,497.5	44.8%

Land use classes	Area (Ha)	Area (%)
Bare Area	27.0	0.001%
Forest	101,712.1	10.8%
Grass	332,472.4	35.3%
Settlement	1,629.4	0.2%
Shrubs	76,695.0	8.1%
Water Bodies	7,256.4	0.8%
Total	941,289.7	
Agriculture	318,760.0	51.0%
Bare Area	868.7	0.1%
Forest	70,777.7	11.3%
Grass	72,462.8	11.6%
Settlement	6,760.2	1.1%
Shrubs	148,268.1	23.7%
Water Bodies	6,953.3	1.1%
Total	624,850.7	

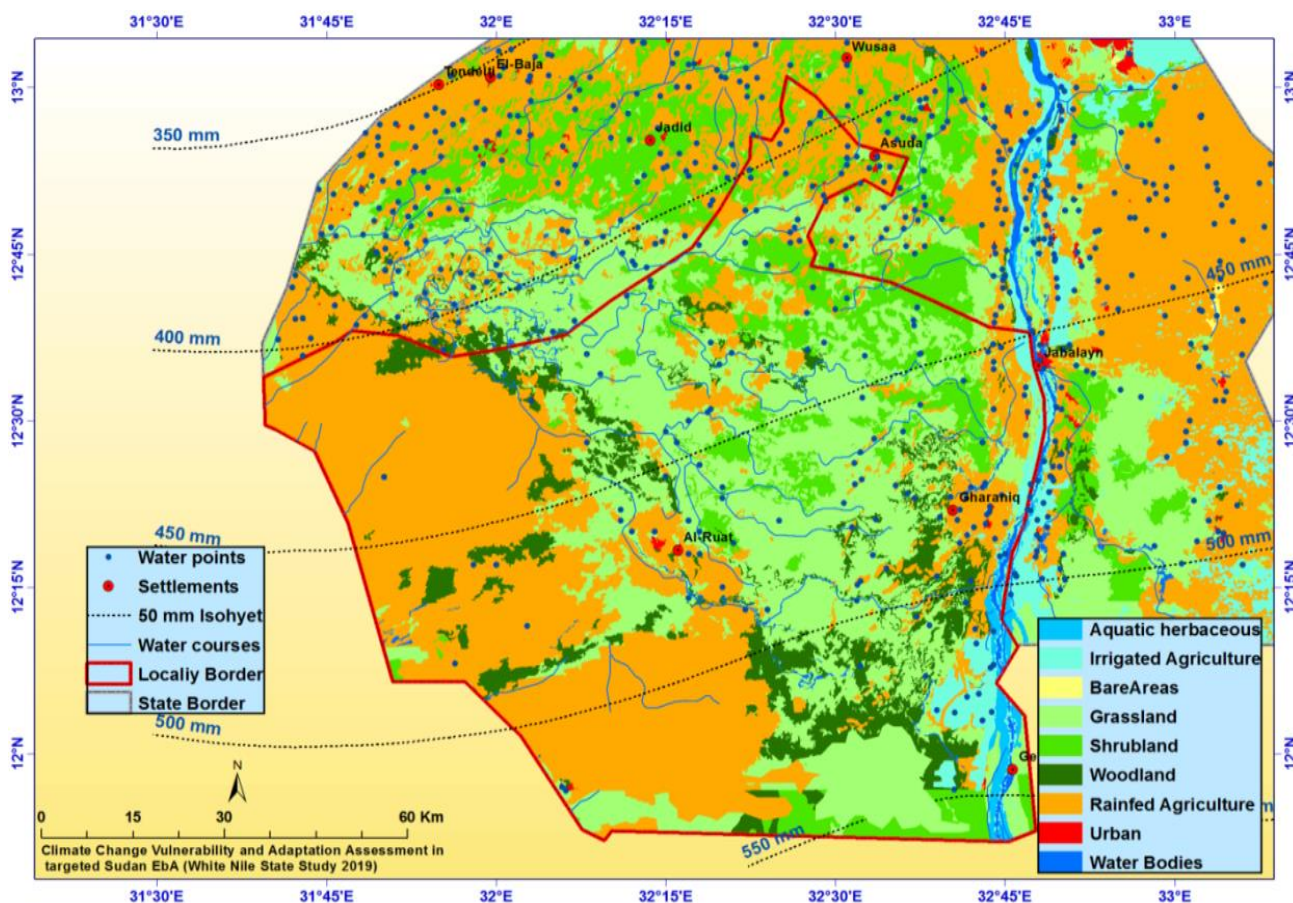


Figure 4. Land Use/Cover (LULC) at Al Salam locality.

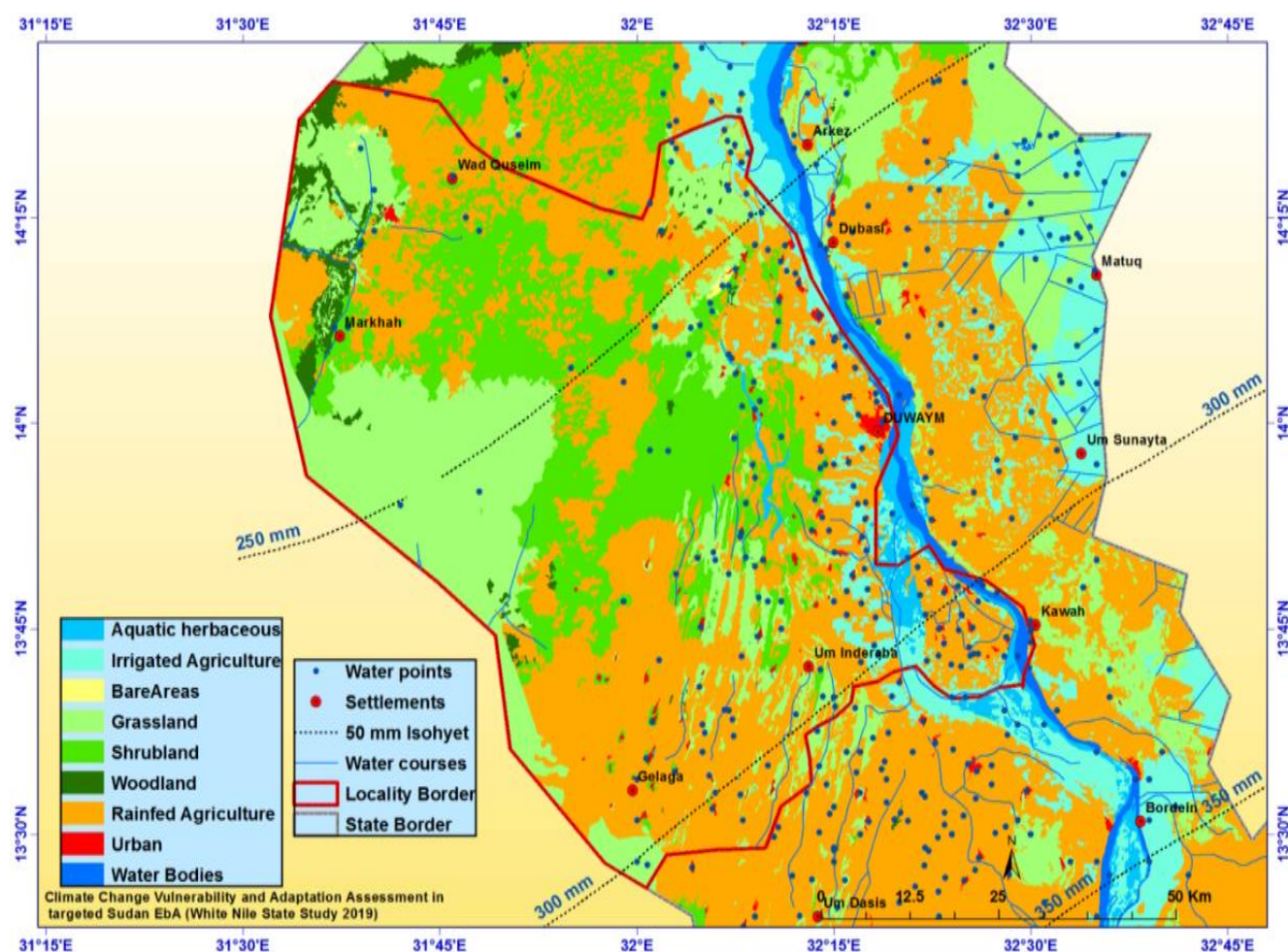


Figure 5. Land Use Land Cover (LULC) at El-Duwaym Locality.

4.3. Vulnerability Classification

The results showed that more than half of Al Salam locality 52% is classified as slightly vulnerable, while 48% of the locality was classified as non-vulnerable (Table 5, Figure 6). Despite the classification of the area as slightly vulnerable there are many climatic and non-climatic factor affected the agriculture, forestry, and range land and food security of the locality. These factors can be summarized in; low and erratic rainfall, expansion of mechanized farming, conversion of forest and range land to cultivated land, tree felling, water shortage especially during the dry season, decrease in crop productivity due to the intensive cultivation and outbreak of pest and diseases.

The results showed that 88% of El Dweim locality has been affected by drought which ranged between moderate to slight drought (Table 7, Figure 5). According to the percentage of area hit by the drought, the locality can be classified as highly vulnerable to climate change. The results from the FGD with the local communities in the targeted villages Elhelba, Agaidat El Tair and Wad Gabur perceive that the climate has changed compared with the past 30 years. They stated that the

rainfall has decreased, the forest cover deteriorated, the soil fertility has declined, and the area was hit by drought several times. The climate change variability that observed in the area during the last 30 years include:- Low and erratic rainfall, desert encroachment shortage of fodder and disappearance of palatable species, decrease in crop productivity, decrease in water sources, decrease in forest covers and disappearance of some tree species and flooding.

Several vulnerability factors rank WNS in general and El Dweim locality in particular as among the most vulnerable areas in Sudan due to climate variability and change. Increased frequency of droughts and high rainfall variability over the past few decades have already put stress on the rainfed agriculture, pastoralist systems and the livelihoods of the rural population in the area. In El Dweim locality, reduction of rainfall, in combination with increased water demand and land use change, has contributed to desertification and depletion of water sources over the past few decades. High population growth adds pressure to an already strained natural resource base.

Drought, desert encroachment and flooding considered as the main climatic hazards that observed during the last 30 year. The last time that the area experienced climatic hazard is the drought of 1984 and flooding in 2007 and 1988. The results

showed that the southern and the western part of Wad Gabur considered as most affected area, in Elhelba the northern part of Jabarouna, Um sunta, Um furrow considered as more vulnerable to climate change in addition Agaidat El Tair, the northern part of the locality also considered as the most vulnerable area. The frequency of the climate change related hazard is variable; in Agaidat Altair the related hazard is happening every 1-3 years, in Wad Gabur it happens somewhat rare once in every 5-10 year, while in Elhelba the drought happens every 1-3 years and the flooding every 5-10 years. Generally, and according to the classification before, the area is more vulnerable to the climate change and this has led to low crop productivity, drought and desertification, deterioration in forest and range land beside the scarcity of water which affect the livelihoods of the local population in the targeted villages. The climate change related hazard has direct effect on crop productivity, range and pasture and animal production which has direct effect on food security and livelihood of the local population. The results showed that in the targeted villages the children are the most affected category by climate change and climate related hazard, followed by women and the elderly people.

Changes in temperature and rainfall patterns represent a pri-

ority threat to food security in Sudan's agriculture-based economy and have caused a shift in the precarious distribution of ecological zones in the productive capacity of rain-fed agriculture. 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 [19].

Formerly semiarid ecological zones, such as the majority of the White Nile State, are gradually moving southward as the climate becomes increasingly arid and hot, thus taking on characteristics similar to the arid zones found further north. For example, severe drought events in 1983/84 -1987 and 1990/91, 2000 and 2003 resulted in declines in livestock populations by 60 to 70 percent in some areas of Sudan (in addition to affecting at least 8 million people during each event). Due to a creeping trend towards drier conditions throughout Sudan, [15] the southern region of Sudan has one of the largest displaced populations in the world [16].

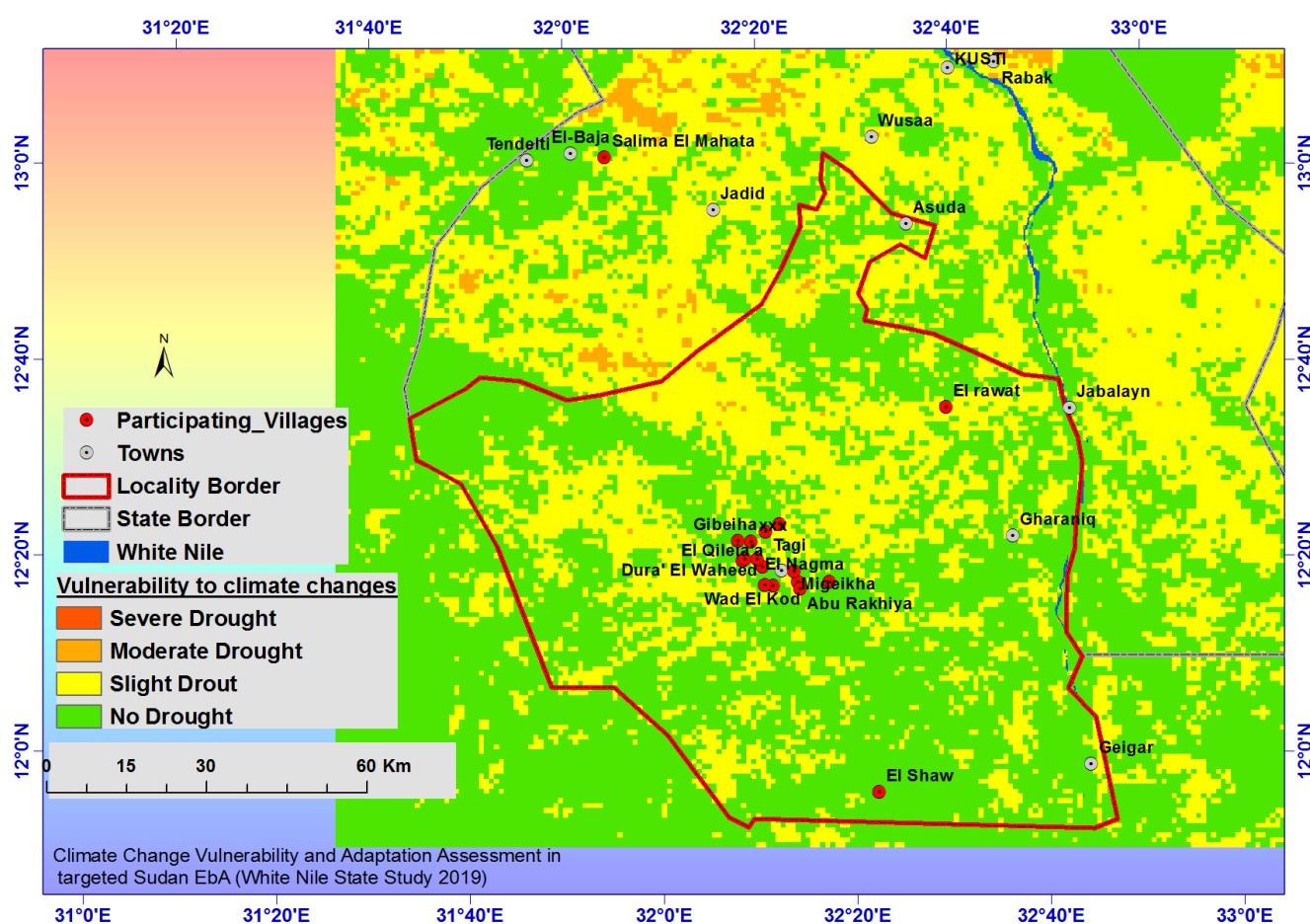


Figure 6. Climate Change Vulnerability at Al Salam Locality.

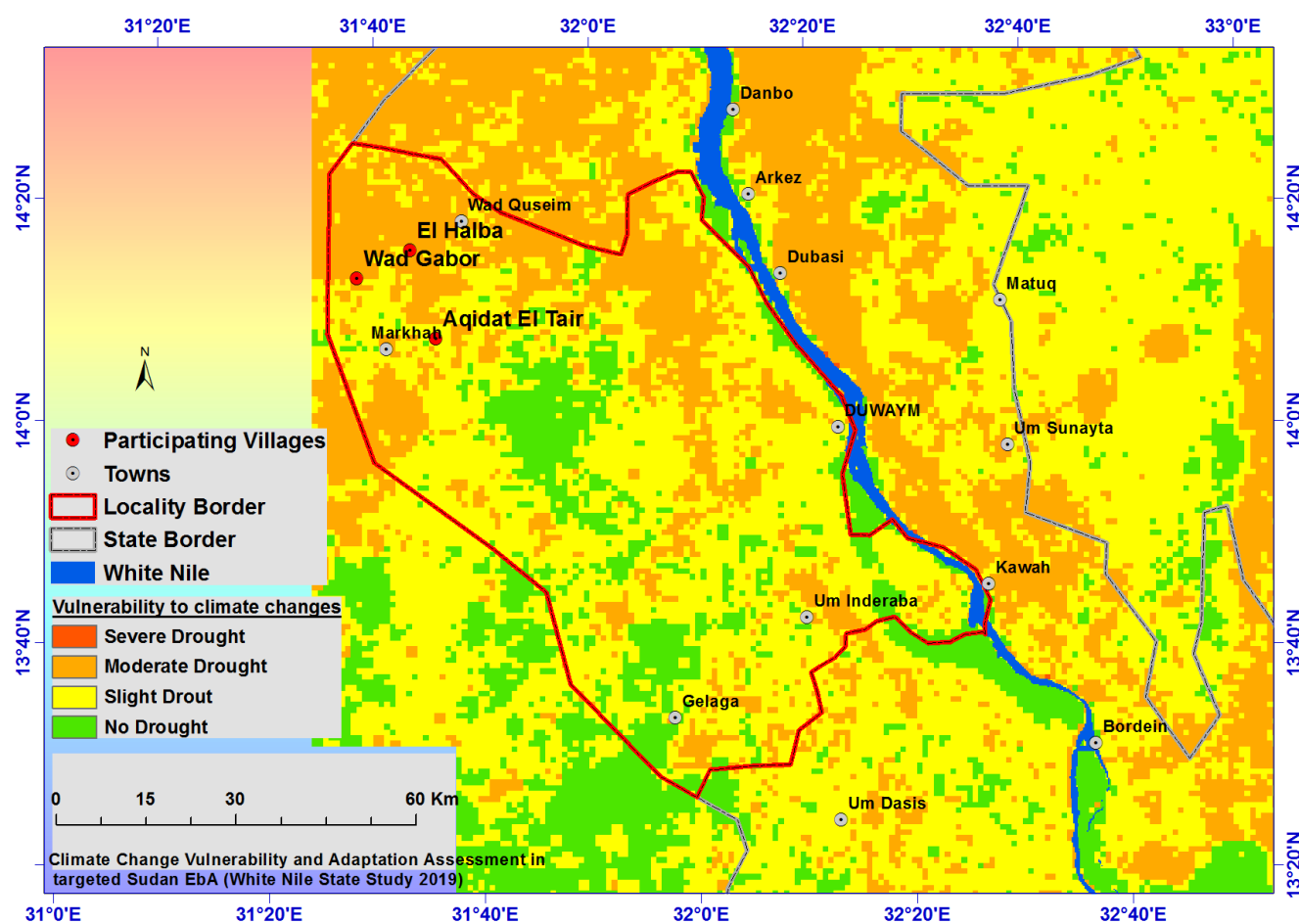


Figure 7. Climate Change Vulnerability at El-Dweim Locality.

Table 5. Areas Vulnerable to Climate Changes in the Targeted Localities.

Drought Index	Area (ha)	Area (%)
Moderate drought	544.8	0%
Slight drought	486,885.3	52%
Non vulnerable	453,859.5	48%
Total area	941,289.7	
Moderate drought	270,957.6	43%
Slight drought	280,746.8	45%
Non vulnerable	73,145.5	12%
Total area	624,849.9	

4.4. Impact of Climate Change Vulnerability in Agricultural Production in the Targeted Localities

The results showed that agriculture is the main source of

income for more than 70% of the population in WNS. The main field crops in Al Salam locality are sorghum (Geshaish and Arfa gdamak), sesame (Ballwa, Bromo, Abu showra), mellit (Dembi), groundnut (Tjarub) and watermelon (on the sandy soil" goz"), and few vegetable crops. The sorghum Arfa gadmak and sesame Bromo (Figure 8) are the only two improve varieties in the targeted villages. The average farm size ranged between 15-30 feddan for sorghum and sesame and 1 Mukhamas for groundnut (1 Mukhamas=1.78 feddan). The average yield of sorghum and sesame ranged between 150-250 kg /feddan, while for groundnut the average yield ranged between 250-500 kg/Mukhamas.

In El Dweim locality the cultivated area is varied from 5 Mukhamas to more than 50 Mukhamas in some areas. Due to climatic change vulnerability crop production was sharply declined in the last 30 years. The main field crops are mellit, sesame, watermelon, sorghum, while wheat and some of vegetables crops are cultivated during the winter season along the White Nile Bank. The cultivated area is ranged between 5-10 Mukhamas for Mellit, 10-20 Mukhamas for sesame, the average yield is varied from 50-200 kg for Mellit and 150-300 kg for sesame. Most of the cultivated varieties are local one except sesame (promo) which was introduced by EbA project.

The climatic and non climatic factors that affected crop production in the targeted villages include; low and erratic rainfall, outbreak of pest and diseases (striga), lack of improve seeds, lack of proper storage capacity, flooding especially in Al salam locality, mono-cropping or sole cropping which lead to soil deterioration and striga infestation in mellit and sorghum fields, lack of financial support, poor extension services, lack of machineries, high wind speed and higher temperature during the summer season, deep ploughing of the sandy soils (goz) which lead to soil erosion, high cost for land perpetration and agricultural operation and higher cost for irrigation in the irrigated schemes. The majority of the interviewers stated that the crop production is not enough to feed their families during the year. They compensate the yield losses by work as casual labour in mechanized schemes; migrate to the big cities searching for work, selling small ruminants (goats and sheep's) to cover their family's needs during the summer season. The results showed that only 30% of the producers in Al Salam locality they use adaptation methods such as water conservation and early mature varieties to increase their crop yield. It was noticed that the farmers in this locality and in other WNS localities need more extension services to adopt the new improve crop production technologies, water harvesting, seeds priming, micro dose fertilizers and other adaption mechanism that maintain the environment and sustain crop productivity.

Households in the Sudan are predominantly rural dwellers, accounting for 73 percent of the population [7]. Among rural households, 58 percent live below the poverty line compared to 27 percent of urban households. Rural households mainly rely on agriculture as their main livelihood – 65.4 percent of the rural population work in agriculture compared to only 8.9 percent in urban areas. The country is reliant on agriculture with the sector accounting for one third of GDP and one-half of foreign exchange earnings and providing livelihoods to

more than half of the Sudanese people [2]. As 93 percent of annually cultivated land in the country is rainfed, such environmental changes are especially important, affecting the entire economy and the livelihoods of all directly or indirectly.

These results are in line with the finding of [8] who mentioned that “White Nile State is severely impacted by the climate change induced droughts and floods. Most notably, increasing temperatures, decreasing trends of annual precipitation as well as increased variability, are causing a gradual shift of climate end ecological zones from north to south”. That is, formerly semiarid ecological zones, such as the majority of the White Nile State, are gradually moving southward as the climate becomes increasingly hotter, thus taking on characteristics similar to the arid zones currently found further north [8]. This situation has adversely impacted water availability and agricultural potential, through increased frequency of droughts, dust storms and heat waves. There is also an increasing frequency of extreme flooding events caused by an increase in intensity of rainfall both during the rainy season and in rainstorms (flash flooding). These climate trends and risks are exacerbated by a number of non-climate issues such as: decreased vegetation cover due to overgrazing and deforestation, and inefficient management of water resources thus further increasing trends of ecological zone shift and desertification [8].

The recommended interventions to improve crop yield in the two localities include dissemination of improve seeds drought resistant and heat tolerance, introduce intermediate technologies (animal drawn implement) for preparation of the sandy soils, introduction of water harvesting techniques and supplementary irrigation, provision of electricity for the irrigated schemes, control of pest and diseases, rising farmers awareness by establishing farmers field schools and support the extension services.



Figure 8. Sesame Demonstration farm in Al Salam Locality.

4.5. Impact of Climate Change Vulnerability in Forest Covers in the Targeted Localities

The results from the satellites maps showed that the forest covers were reduced by 68% in Al Salam locality. The initial forest area was estimated at 365,726 ha in 2000 and due to the climate change variability and other non-climatic factors, the area was reduced to 147,089 ha (-68%) in 2018 by conversion of 250,282 ha of forest land to non-forest areas including 151,231 ha (41%) to cultivated land and 94,950 ha (26%) to grazing or range land, Table 6. Generally, the deterioration in forest land was occurred in the eastern and northern parts of the locality, whereas forest clearance occurred in most parts of the locality (Figure 9).

The main tree species are Ketir (*Acacia mellifera*), Laout (*Acacia nubica*), Kadad (*Dichrostachys cinerea*), Sunt (*Acacia nilotica*), Hegligh (*Balanites aegyptiaca*), Sidir (*Ziziphus spina-christi*), Hashab (*Acacia senegal*) and Talih (*Acacia seyal*). The results showed that the majority of the respondents (90-100%) depend on the forest biomass (firewood and charcoal) as a main source of energy. It worth mentioned that some villages depend 100% on forest biomass as a main source of energy.

The results from the satellite images showed that the initial forest cover in El Dweim locality was very low Table 7, estimated at 963.4 ha in 2018 compared with 28,411 ha in 2000. The results showed that 27,833 ha of grassland were converted to shrubs at the western parts of the locality as illustrated in Table 6, Figure 7. The maps below showed the conversion of forest land into agriculture, range, urban land, tree cutting/pare land and water bodies.

The main tree species at El Dweim locality are Seyal (*Acacia tortilis*), sumor (*Acacia radiana*), Heglig (*Balanites aegyptiaca*), Sidir (*Ziziphus spina-christi*), Marakh (*Bosciasenegalensis*) and Haraz (*Fedherbia albida*). The results showed that the climatic factors that affected forestry sector in the targeted communities include low and erratic rainfall, flooding and rising in temperature during the summer season, expansion of the cultivated land into the forest land, illicit cutting for fuel wood and charcoal production, drought and desertification.

These results are in line with the finding from baseline study which indicated that El Salam and El Dweim localities

are representing the highest percentages for use of forest biomass. The highest proportion of wood use by the targeted community in Elsalam and El Dweim localities (91.9%) and (85.7%), El Dweim is also shown the highest percentage of charcoal use (70%) by the local people, followed by Tendalti (60.2%) and Elsalam (45.4%) [11].

The forest cover in Al Salam locality was highly affected by climate change. This result are in line with the finding of Ministry of Agriculture report in (2012) who attributed the deterioration in forest and range lands to the expansion of un demarcated rain fed farming which closed the animal routes between rainy seasonal grazing land and summer grazing land. The expansion of cultivation areas into forest and rangeland may force pastoralist to concentrate on small land and putting more pressure on it and this will lead to serious environmental problems. Moreover, the cultivated land had increased due to a change of an economic activity, that is, from pastoralist to farming. Large number of population in the rural areas is forest dependent using the forests for various livelihood support including on farm trees, feed for livestock, wood harvesting and collection of NWFPs inclusive of aromatic, culinary and medicinal plants. For small-scale farmers, gum Arabic represents a diversification strategy to mitigate crop failure and a way to meet household's cash needs. Furthermore, most of the energy consumed in the Sudan (about 80%) is obtained from the trees, as documented by the demand survey [1, 4].

The suggested communities interventions from FGD include; forest protection, providing of forest seeds, establishment of shelter belts and wind breaks, introduction of solar energy for lighting and cooking, water harvesting techniques, rehabilitation of the degraded forests by adopting agroforestry systems (Tungya), provision of improved stoves and LPG cylinders, increase communities awareness in forest protection and tree planting. The Suggested interventions from the Forest National Corporation (FNC) include; re-inventory and reservation of the forest land, rehabilitation and maintenance of the forest office and the guest house, establishment of forestry camps in some forests by using local materials, support the forest guards by foods, mosquito nets, plastic sheets, increase the number of forest guards, maintenance of the existing forestry vehicles, collection and provision of forest seeds (Hashab, Sidir, Sunt), rehabilitation of the nurseries and establishment of new ones and support forestry extension services by providing multimedia projector and Generators.

Table 6. Cross-Tabulation Matrix of Rangeland and Forest in El Salam Locality Between 2000 and 2018 (Values in Hectares).

Land use (Ha)	Rangeland	Agriculture	Water bodies	Urban	Forest	Land use 2000
Rangeland	40,972.1	198,076.0	1,045.5	965.0	23,643.6	264,702.3
Agriculture	4,682.6	292,248.6	2,171.4	321.6	7,921.5	307,345.6
Water bodies	212.0	40.1	3,136.4	-	-	3,388.5

Land use (Ha)	Rangeland	Agriculture	Water bodies	Urban	Forest	Land use 2000
Urban	46.1	-	-	-	80.4	126.5
Forest	94,950.0	151,231.0	3,297.2	804.1	115,443.9	365,726.2
Land use 2018	140,862.8	641,595.7	9,650.5	2,090.8	147,089.4	

Table 7. Cross-Tabulation Matrix of Rangeland and Forest in El Dweim Locality Between 2000 and 2018 (Values in Hectares).

Land use (Ha)	RangeLand	AgriCuture	Urban	WaterBodies	Forest	Baresoil	Land use 2000
Rangeland	254,874.3	252,141.8	3,363.1	718.2	27,832.8	578.0	539,508.2
Agriculture	14,363.1	61,410.9	700.6	2,715.0	-	-	79,189.5
Urban	105.1	840.8	963.4	105.1	17.5	-	2,031.8
Water bodies	175.2	175.2	17.5	2,785.0	-	-	3,152.9
Forest	315.3	-	-	87.6	560.5	-	963.4
Bare soil	-	-	-	-	-	-	-
Land use 2018	269,832.9	314,568.6	5,044.6	6,410.8	28,410.8	578.0	

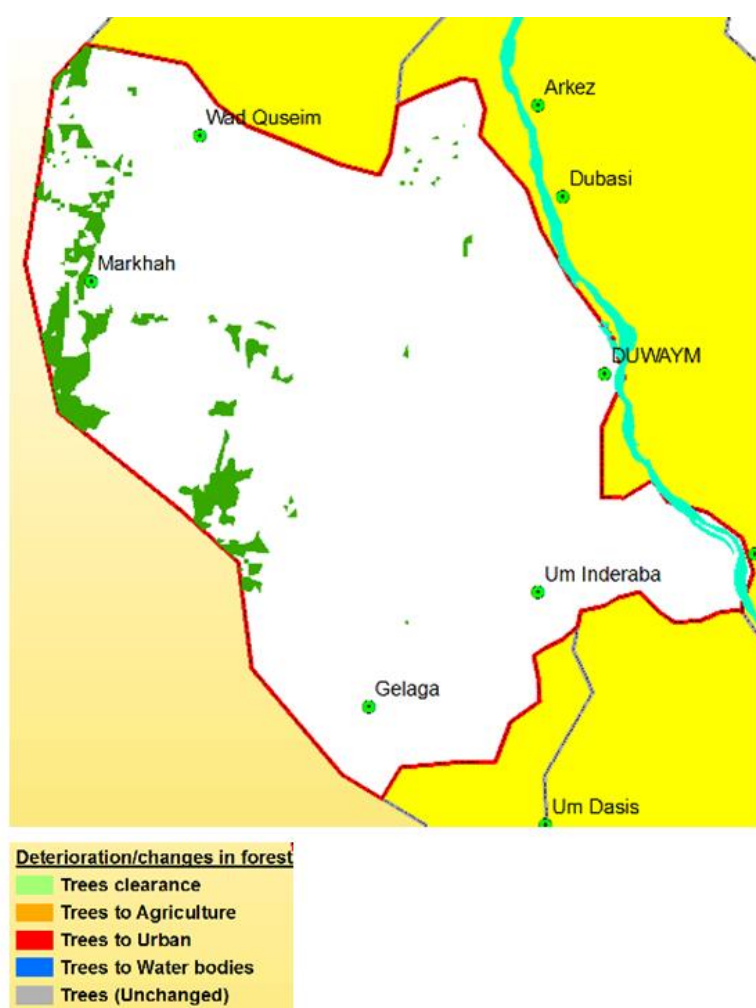


Figure 9. Identification of Changes/Deterioration in Forest Covers Between 2000 and 2018.

4.6. Impact of Climate Change/Variability on Range Land in the Targeted Localities

The results of the remote senses images from 2000 to 2018 and Cross-tabulation confusion matrix showed that the initial rangeland in Al Salam locality in 2000 was estimated at 264,702 ha. By year 2018 almost 85% of these areas were converted to non-grassland as follows: 198,076 ha (75%) to agriculture and 16,000 ha (10%) to urban areas, water bodies and shrubs such as Laot (*Acacia nubica*). Table 7 and Figure 10 showed the deterioration and conversion of range and pasture land to cultivated land and urban settlements.

Most of the interviewed households perceived that the climate was changed in the area and they concluded that palatable range land species are disappeared and forest cover was deteriorated. The results showed that most of range lands in El Dweim locality are occupied by un-demarcated rain fed farming; the expansion of cultivated areas into rangeland has closed the animal routes between rainy seasonal grazing land and summer grazing land.

The satellite images and remote sensing data (Table 8 and Figure 11) showed that initial rangeland in El Dweim locality in 2000 was estimated at 539,508 hectares, which was decreased by more than 52% in 2018. Most of these areas were converted to non-grassland as follows: 252,142 ha (46.7%) to agriculture land and 32,492 ha (6%) to urban areas, water bodies and bare land. The results showed that the most important range species in El Dweim locality are Tommam (*Panicum turgidum*), Haskneetkeshin (*Cenchrus biflorus*), Haskneetnaim (*Cenchrus ciliaris*), and Gao (*Aristida spp*).

The changes in range land conditions could be attributed to the uncontrolled expansion of mechanized and traditional rain-fed agriculture on grazing lands.

The present investigation showed that the communities in

the targeted villages attributed the deterioration in range land to many climatic and non climatic factors such as low and erratic rainfall, flooding, expansion of cultivated land, drought and desertification especially in the northern and western part of state and lack of water during the dry season beside the uneven distribution of water points. They stated that the range grasses is the main sources for animal feeding during the rainy season but it's not enough to feed their animals in the dry season. The results showed that the palatable species was decreased in the study area. The most palatable species that were found in the targeted area are Tabar (*Ipomea spp*), Tagtaga (*Vigna sun-hum*), Gtgate (*Geigeria alata*), Reiha (*Ocimum basilicum*), Um chirr (*Brachiaria obtusiflora*) and Biad (*Commelina spp*), Koreeb (*Brachiaria xantholeuca*). The interviewers stated that the invader species in the study area were increased. These species include *Corchorus sp*, Adar (*Sorghum sudanense*), Drissa (*Tribulusterstris*) and Moleita (*Launaea cornuta*).

The recommended intervention include; broadcasting of palatable species, adoption of harvesting techniques (hafirs, donkeys, hand pumps), supplementary animal feeding, introduction of deferred grazing system, provision of animal vaccines and support the veterinary services, opening of animal tracks, develop coordination mechanisms between the range administration and other NGOs who working in same field, formation of route patrolling teams, to observe the situation along the routes before movement of nomads and to report violations to locality committees or to the local authorities to avoid conflicts, support range extension through provision of extension equipment and materials, demarcation of rangelands boundaries and involvement of the local communities in planning, implementation and evaluation of range improvement and rehabilitation programs.

Table 8. Cross-Tabulation Matrix of Rangeland and Forest in El Salam Locality Between 2000 and 2018 (Values in Hectares).

Land use (Ha)	Rangeland	Agriculture	Water bodies	Urban	Forest	Land use 2000
Rangeland	40,972.1	198,076.0	1,045.5	965.0	23,643.6	264,702.3
Agriculture	4,682.6	292,248.6	2,171.4	321.6	7,921.5	307,345.6
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Urban	46.1	-	-	-	80.4	126.5
Forest	94,950.0	151,231.0	3,297.2	804.1	115,443.9	365,726.2
Land use 2018	140,862.8	641,595.7	9,650.5	2,090.8	147,089.4	

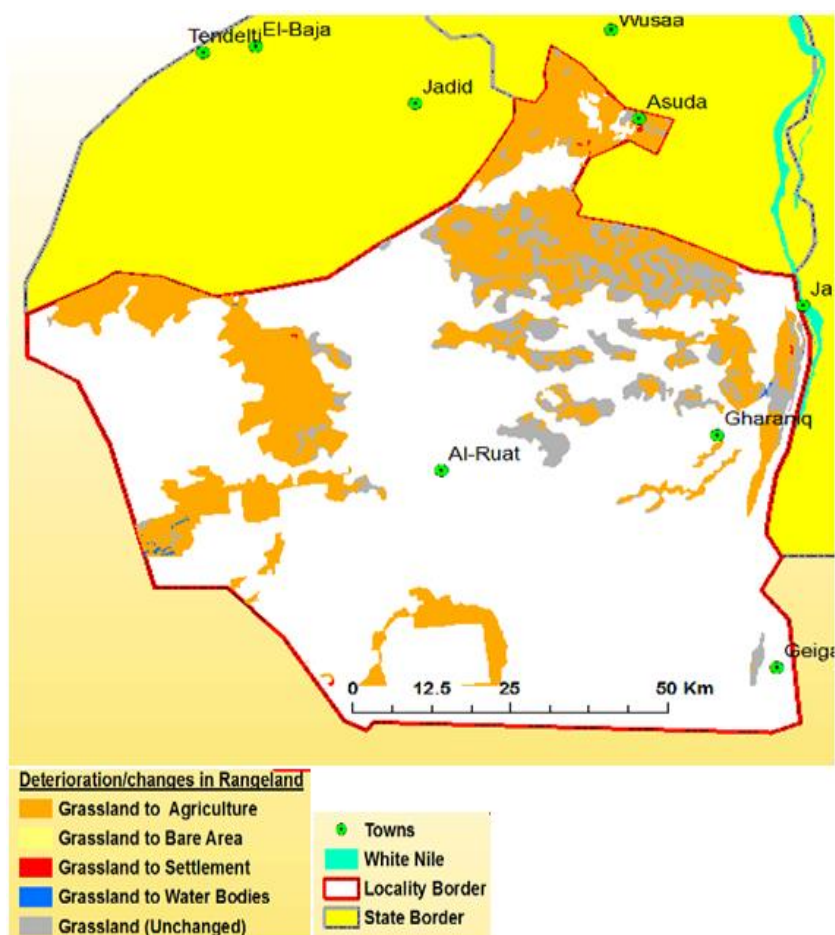


Figure 10. Changes in Range Land Between 2000 and 2018 in Al Salam Locality.

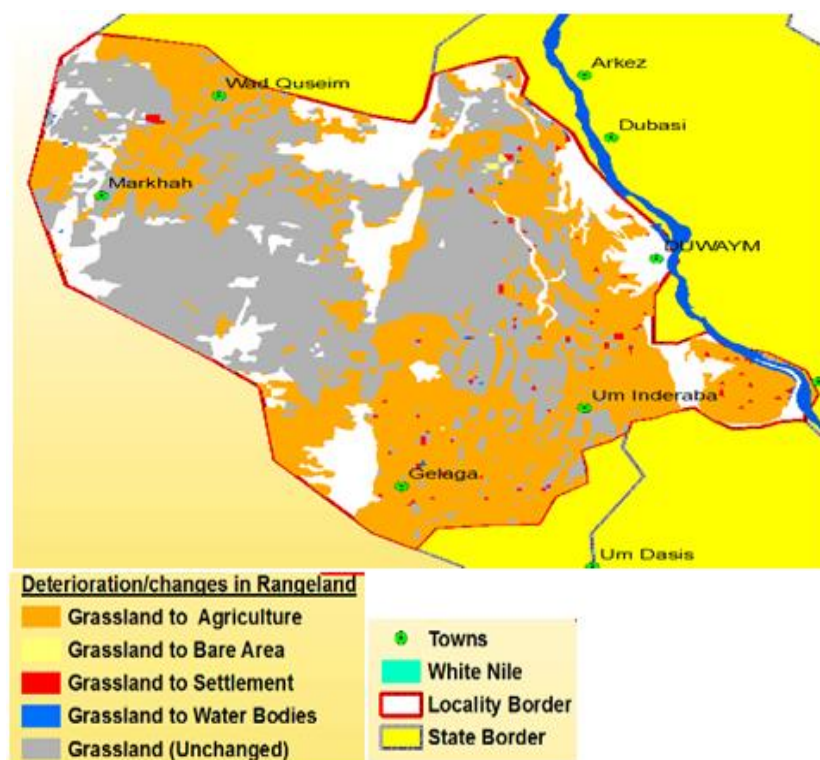


Figure 11. Changes in Range Land Between 2000 and 2018 in El Dweim Locality.

4.7. Climate Change and Coping Mechanisms at the Targeted Localities

Community members in the targeted localities perceive that the climate was changed and they have a clear idea about the factors that lead to the climate change and their impact on their livelihoods, they aware about the effect of these changes in its relation with the decrease of water sources and drinking water scarcity, low agricultural land productivity, deterioration of the natural habitat and the disappear of many of the plant and animal species. The locality was hated by drought in 1953, 1984, and 1985, 1991 and 1992 and flooding in 2005, 2012, 2014 and 2019 the impact of these catastrophic lead to displacements, death of people and animals (Table 9). The coping strategy depends on forest non timber products (NTFPs) which provide essential resources during emergency periods (floods, droughts and famines). In famine periods, roots, tubers, rhizomes and nuts are most preferred. They are characteristically energy rich, but often require prolonged processing. Sudanese forest fruits are used traditionally as foods as well as medicines. Doum (*Hyphaene thebaica*L), kirkir (*Randia ageipaeiflora*), karmadoda (*Nauclea latifolia*) and gudeim

(*Grewia tenax*) are some of the indigenous fruits of the Sudan. These forest fruits were found containing adequate amounts of minerals. People in Al Salam locality during the famine period depend on NTFPs as a main source of food they collect Makhait fruits *Boscia senegalensis* boiled the fruits and powdered to make Asidaa, other fruits used include gudeim and Kuraeib.

Similarly, Saada, 2019 reported that the case of climate change along with concerned local people in WNS showed a wider and dramatically changes in the areas since the establishment of the oldest villages in 1969. These changes are described by the communities as negative and it is common and similar in all the targeted communities, it includes reduction in the rain fall ratios, and rainy seasons become shorter compared with the past ten years. In addition to this people noticed that some natural water resources are disappeared. Many people are changing their livelihood income sources, they cultivate more than crop in their farms, they shift to smaller animal types e.g. sheep and goats, they reduce the number of daily meals, use of improved seeds, selling their animals, while some of them either purchase fodder or take their animals to the neighboring relatives.

Table 9. Climatic and Non-Climatic Events in the Targeted Localities in WNS.

Event	Years	Impact	Copping strategy
Drought	1953	Decrease in crop production and productivity, deterioration in rangelands, deterioration in forest covers, disappearance of some rangelands plants, Migration of wild animals	Collection of wild fruit trees, displacement to big cities
	1984		
	1985		
	1991		
	1992		
Flooding	2005	Destruction of basic infrastructure, houses, hospitals, water sources, market place, damage to farm and rangelands, crop failure, outbreak of pest and diseases	No specific coping strategy were mentioned
	2012		
	2014		
	2019		

5. Conclusion and Recommendation

Forestry in the WNS showed considerable deterioration due to many climatic and non climatic factors especially in Al slam locality. The results from the satellites maps showed that the forest covers were reduced by 68% in the locality. The study recommended; planting of 10% of the area of the agricultural land with forest trees; establishment of shelterbelts, promotion of social forestry or community forestry, enforcement of forest laws, rehabilitation of the degraded forests, establishment of villages nurseries, introduce solar energy to reduce the dependency on forest biomass. For Range land the recommendation includes; rehabilitation of rangelands by dis-

tribution of palatable species, controlling of invader plant, improve grazing management systems.

Abbreviations

AI	Aridity Index
FGD	Focus Group Discussion
HNO	Humanitarian Needs Overview
IDP	Internally Displaced People
KII	Key Informants Interview
LST	Land Surface Temperature
LULC	Land Use And Land Cover
MoA	Ministry of Agriculture
MODIS	Moderate Resolution Imaging Spectroradiometer

NDVI	Normalized Difference Vegetation Index
WNS	White Nile State
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.

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