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Production of Browse Trees/Shrubs under Climate Change Conditions in the Butana Rangelands of Sudan

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Abstract:

The study was conducted in the Butana region of Sudan to assess the impact of climate change on the browse trees/shrubs cover and production in the Butana rangelands. Five meteorological stations surrounding Butana were selected to represent the region's climate. Simple regression analysis was used to analyze the trend of climate variables (rainfall, temperature). The direct count method was used to measure browse production and a social survey was also conducted to assess farmers' perceptions on climate change. Rainfall for all meteorological stations showed a decrease in monthly and annual rainfall during 1961-2013. Annual temperature analysis indicated a noticeable increase in maximum and minimum rates at all meteorological stations since 1985. All interviewees agreed that trees/shrubs cover had decreased compared to the past. Significant differences ($P < 0.05$) were found in browse production between the sites during the dry (no rainfall) season. The average browse production of three sites was 310, 236, and 297 kg/ha for the wet season and 247, 95, and 85 kg/ha in the dry season for El-Idaidat, El-Bahoogi, and Wad-Shamoon sites, respectively. The variation in browse production between sites was linked with tree density/ha, which was directly affected by decreasing in rainfall and increased temperatures. Seed banks in Ewerdaidat were 4 seeds/m^2 while 3 seeds/m^2 were found at El-Bahoogi. The study concluded that there was a decrease in rainfall and an increase in temperature during the last decade in the Butana, reflected negatively on trees/shrubs cover and its browse productivity.

Keywords: Acacia; Butana; Browse; Climate change; Trees/shrubs.

1. Introduction

Sudan is highly impacted by climate change. Most regions are sensitive to rainfall and temperature changes (Nadir et al., 2014; Zaki-Eldeen and Elhassan, 2015). Frequent drought spells and desertification resulting from climatic change are Sudan's biggest challenges (Khiry and Csaplovics, 2005; Siddig et al., 2020). Butana rangeland has been exposed to climate change and drought events during the last periods. Rainfall isohyets shifted towards the Southern part of the region by about 89, 46, and 23 km for the 100, 300, and 500 mm isohyets, respectively (Elhag, 2006). The pastoral resources in the region are altered under the mutual effect of climatic factors and human activities such as the removal of natural plant cover (Sulieman and Ahmed, 2013) as well as the impact of governmental policies that prefer farming crops in contrast to pastoralism (Sulieman, 2018). The decreasing rainfall is recognized as the original power-altering plant type in the Butana rangeland (Sulieman and Ahmed, 2013). Due to climate change, tree/shrubs cover and pastures in the Butana have declined remarkably (Elhag, 2006). The degradation of Acacias (the most preferred browse species) in the Butana is related to the decrease of annual rainfall amounts (Alredaisy and

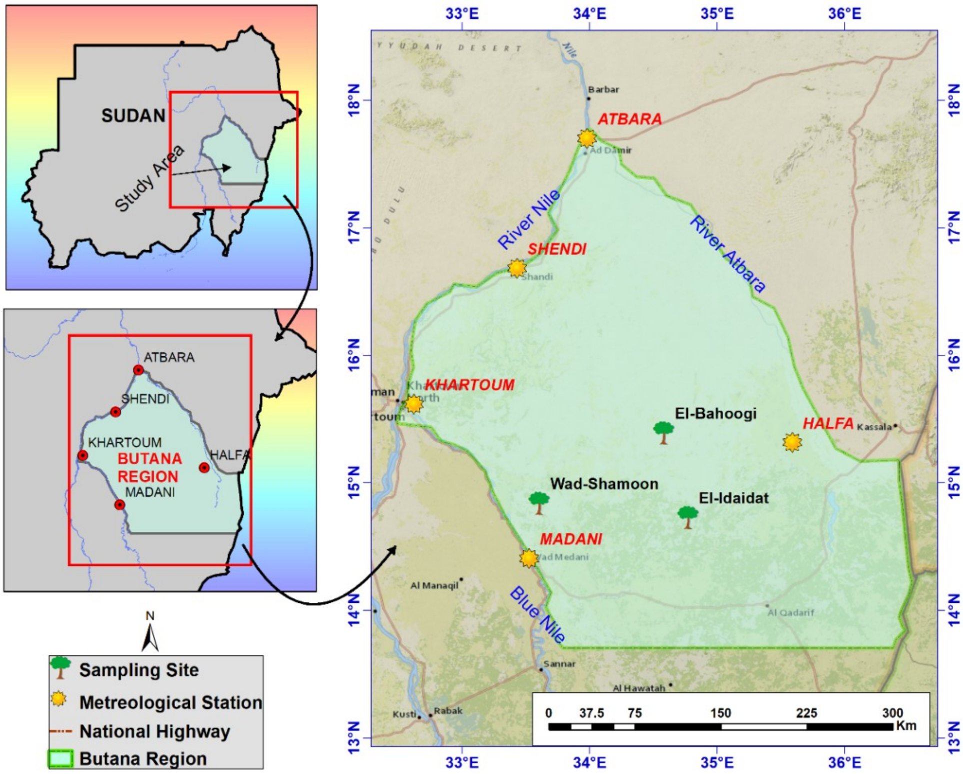

Figure 1. Map of Butana region in Sudan.

Zubair, 2011). In addition, climatic change is projected to affect the seed bank in the soils of Acacia trees (Pramanik et al., 2017). Up warding temperature levels negatively affect seeds viability and lead to seedling mortality (Lloret et al., 2004). Moreover, variability in rainfall leads to quick germination, fewer seedlings' survival, and changed plant species patterns (Wilson, 2015). As a result of these alterations, a change in the composition, densities, and vegetation cover in the Butana can occur (Fordham et al., 2012).

Browse trees and shrubs have a vital source of forage for livestock (Franzel et al., 2014; Mbatha and Bakare, 2018) at inadequacy times of herbaceous forage (Ffolliott et al., 1994; Devendra, 1990). Many pastoral groups in the arid and semi-arid normally-cut branches and twigs from various tree/shrub species (*Acacia seyal*, and *Acacia mellifera* in particular) to make the browse reachable to livestock during the dry season (Abdalla et al., 2017). Furthermore, browse species are active resources of use of negligible land on which regular crop farming is ineffectual owing to climatic, topographic or edaphic restrictions (Le Houerou, 1984). The importance of browse trees and shrubs to the people in arid and semi-arid lands can be explained in varied situations: normal scarcity, extended drought, and concentrated fodder production (Abdalla et al., 2017). For example, *Acacia tortilis* (Sayal) is the most preferred browse tree in semi-arid areas, especially during dry periods. It is preferred by animals and contributes to soil improvement. Acacias in the Butana region can exist for a long period and are the main sources of fodder for livestock in the area. The people surrounding the Wad Kabo forest in the Butana indicated that their livestock depends on the forest as the main rangeland for grazing and browsing (Ibrahim, 2010). *Acacia tortils* (Sayal) and *Acacia mellifera* (Kitir) provide fodder for livestock in critical periods when grasses and herbs are not available. These species form useful and valuable fodder, especially for camels and goats in terms of crude protein and some nutritive elements like Na, K, and Ca. In addition, *Acacia mellifera* (Kitir) has been considered the most important browse tree in the Butana region (Abdelmalik et al., 2015).

Most climate change studies in Btana have emphasized the impact of climate change on annual agricultural crops and neglected its effect on browse trees/shrubs. Therefore, this study aims to evaluate the climatic change effect on the browse trees/shrubs (particularly *Acacia mellifera* (Kitir) and *Acacia tortilis* (Sayal) and its fodder production in the Butana rangelands of Sudan.

2. Materials and methods

2.1 Study area

The study was carried out at three sites in the Butana region that lies on the East-Northern part of Sudan between latitudes 12°30806 -16°30453 N and longitudes 33°35591 -36°35209 E (Fig. 1). These sites (Table 1; Fig. 1) are El-Bahoogi, El-Idaidat, and Wad-Shamoon forests. Sites were selected under consideration of rainfall variation and the dominance of tree/shrub species in the region. El-Idaidat site is located in the southern part of the Butana region, with more than 350 mm of annual rainfall. The main tree/shrub species in this site are *Acacia mellifera* (kitir) and to a less extent, *Acacia nubica* (Laout). This site of the Butana region is inhabited by agro-pastoralists who mainly practice

Table 1. Sites of the study area within the Butana region in Sudan.

site	location within Butana	altitude (m)	average rainfall (mm)
El-Idaidat	south	555	<350
El-Bahoogi	center	654	>250
Wad-Shamoon	west	432	<250

rainfed agriculture to produce sorghum, besides considerable livestock-raising activities. El-bahoogi site is situated in the middle part of Butana (8 km from Es Sobagh, the capital of the Butana region). *Acacia mellifera* (kitir) and *Acacia orefota* (laout) tree species are dominant, with less than 250 mm of annual rainfall. Wad-Shamoon is located in the western part of Butana (27 km from Ruffaa town) with an area of 4,835 ha, and more than 250 mm annual rainfall. The dominant tree species in this site is *Acacia tortilis* ssp *radiana* (Sayal). All these 3 sites represent important rangelands for the Butana people, particularly during the year's dry season (November to April). Goats and Camels represent the main animals that browse the trees/shrubs in the Butana rangelands. In Butana, rainfall occurs only in the wet season from July to October.

2.2 Data collection

2.2.1 Climate data (rainfall and temperature) analysis

To find out whether there is climate change or not, five meteorological stations located around Butana were selected to represent the climate (rainfall and temperature) of the region. These stations include Shandi, Atbara, Halfa, Wad-Wad Madani, and Khartoum. Shandi and Atabara represent the northern part of Butana, Khartoum and Wad Madani covering the western side, while Halfa represents the eastern side of the region.

Data on monthly and annual rainfall and temperature (maximum, minimum) were used to assess climate change and variability. The metrological data for 1961-2013 for the above-stated weather stations around the Butana region were used for this analysis.

Social Survey: A social survey was conducted to identify people's opinions about the impact of climate change on browse trees and shrubs. A total of 150 respondents (from 15 villages distributed in the different parts of the Butana region) with different ages and groups (male and female) were interviewed using a questionnaire. Most of the information gathered was regarding climate change and its impact on tree/shrub cover in the region. Social data were analyzed using the SPSS program, and cross-tabulation and Chi-square tests were applied.

Field inventory: Field data were collected during two field trips over two seasons in 2013 (dry – November to April, and wet season – May to October) to collect bio-physical data. Three sites (El-Bahoogi, El-Idaidat, and Wad-Shamoon) across the Butana rangeland were identified for the browse measurements.

At each selected site, two areas (browsed and un-browsed) were marked. The diameters at the browsing point and browsing level were determined in the browsed area. In the un-browsed areas, three circular sample plots, each of an area of 1000m^2, were laid out on each site. The plots were selected randomly. These circular plots were located using a radius of 17.81 m. All trees inside the circle were given a number and marked. Then, a random sample of 5 trees was chosen inside the circle for browse measurements.

In each plot, tree number and regeneration were recorded, and then, the diameter at the browsing point was determined for the five twigs on each of the 5 randomly chosen trees. Five twigs were clipped randomly from the various directions of chosen trees. The collected information was recorded in a data sheet. The clipped twigs were placed in paper bags and brought back to the lab for drying and weighing. These twig samples were dried using an electric oven at 105 °C for 17 hours and weighed by digital balance; then, browse production was identified using the direct count method by multiplying the twigs' average weight by the total estimated number of twigs/tree.

2.2.2 Soil seed banks sampling

Soil seed banks were sampled randomly across the three sites of the study. The soil sampling was done as (1×1 m) and with 10 cm depth. Three samples were taken from each site. Each sample was placed in a separate soil bag. Soil seed banks were well prepared. Samples from each site were mixed, and then, seeds of trees and shrubs were separated

Table 2. Average rainfalls (by decade) at meteorological stations bordering Butana (Data from Sudan Metrological Authority SMA for the period 1961-2013).

	Meteorological stations				
decades	Wad Madani	Halfa	Shendi	Atbara	Khartoum
1961-1970	355.9	227.0	104.9	58.9	187.1
1971-1980	297.4	329.1	75.0	55.5	129.3
1981-1990	281.0	164.3	48.5	46.2	104.4
1991-2000	259.9	295.5	77.2	52.0	130.4
2001 - 2013	265.4	265.4	85.6	32.3	132.9
mean	291.9	256.3	78.2	49.0	136.8

Table 3. The trend of the annual and monthly rainfall and their significance levels (p<0.05) in the five weather stations around Butana (Data from SMA).

location	**annual rainfall**		**monthly rainfall**	
	trend	P value	trend	P value
Khartoum	-1.226	0.128	-0.136	0.128
Halfa	-0.109	0.803	-0.047	0.811
Wad-Wad Madani	**-1.761**	**0.016***	**-0.220**	**0.016***
Atbara	**-0.626**	**0.004****	**-0.089**	**0.004****
Shandi	-0.260	0.611	-0.037	0.611

*'** = Significant level 0.05 and 0.01 respectively.

physically from the soil using a sieve. Large particles of soil were washed. Then, all seeds found were counted and sorted into two groups, dead and viable seeds, by observing and planting the seeds in the nursery. Seeds density was computed/m^2 using the following formula (Fangama, 2006): Density/m^2 = number of seeds in the area measured

2.3 Data analysis

Statistical Package for Social Sciences (SPSS; Version 20.0) was used for the analysis of variance (ANOVA) (Steel and Torrie, 1980). In addition, simple regression model analysis was used to assess the average minimum and maximum annual temperature trend for the five meteorological stations bordering the Butana region.

3. Results

3.1 Climate trends and variability in the Butana region

3.1.1 Rainfall variability

The study results indicated an extreme decline in rainfall during 1981 – 1987 in the Butana region. Khartoum and Atbara meteorological stations showed the highest rainfall in the year 1988 While the highest annual rainfall for Wad Madani, Shendi, and Halfa stations happened in 1967, 1999, and 1993, respectively (Table 2).

3.1.2 Rainfall trends

Results of time series analysis of rainfall data for the five meteorological stations located around the Butana region showed a remarkable decrease in the monthly and annual rainfall trend during 1961-2013 for all meteorological stations (Table 3). The decrease in annual rainfall for Khartoum, Shandi, and Halfa was not significant whereas for Wad-Madani and Atbara, it was significant (Table 3). The monthly and annual rainfall patterns showed annual variability and decrease (significant for Wad-Madani and Atbara) for all five metrological stations located around Butana since 1985.

3.1.3 Temperature trends

Concerning temperature, there has been a noticeable upward trend of maximum and minimum temperatures (Table 4) in all meteorological stations around the Butana since 1985, with the trend decreasing for the annual minimum temperature at Shandi meteorological station. The results of the regression model analysis of minimum annual temperature showed a significant increase in minimum annual temperature at Madani meteorological station. However, the maximum annual temperature showed a significant increase in Madani, Atbara, and Shandi meteorological stations (Table 4).

3.2 Assessing farmers' perceptions on climate change

The whole 150 respondents from the three sites within Butana agreed that there was a worse change on trees/shrubs cover (in quality and quantity) compared to the past status in the Butana rangelands (Table 5). 50% of the interviewed respondents attributed the noticeable change in trees/shrubs cover to the remarkable decrease in rainfall amounts while 16.7% considered overgrazing a main cause of change. 1.7% think the expansion of rain-fed agricultural areas into rangelands is the essential factor affecting tree/shrub cover in the Butana rangelands. The rest of the respondents (32%) considered all these factors together to be responsible for the vegetation change in the area (Table 6).

Table 4. Trend of average minimum and maximum annual temperature for the five meteorological stations bordering the Butana region (Data from SMA).

location	**minimum annual temperature**		**maximum annual temperature**	
	regression equation	R^2	regression equation	R^2
Khartoum	y = 0.02x + 22.29	25%	y = 0.01x + 37.22	2%
Halfa	y = 0.02x + 19.96	18%	y = 0.01x + 37.46	6%
Madani	**y = 0.03x + 20.64**	**48%**	**y = 0.03x + 33.67**	**46%**
Atbara	y = 0.01x + 22.11	10%	y = 0.03x + 20.65	34%
Shandi	y = -0.01x + 22.07	1%	**y = 0.03x + 36.97**	**46%**

Table 5. Comparison of previous and current status of trees/shrubs cover in the Butana region of Sudan (According to respondents).

status of tree cover	previous (1960 -1980)		present (1981 –to date)	
	count	%	count	%
good	134	89.3	7	4.7
medium	11	7.3	46	30.7
bad	5	3.4	97	64.6
total	150	100%	150	100%
Chi-square (χ^2)	0.003		0.018	

3.3 Assessment of available Browse and its response to the climate change

This study focused on two browse tree/shrub species in the Butana rangeland, namely *Acacia mellifera* (Kitir) and *Acacia tortilis ssp. radiana* (Sayal) which comprise the most important browse resources in the region. The available browse production for both seasons (dry, wet) for *Acacia mellifera* (Kitir) and *Acacia tortils ssp. radiana* (Sayal) is shown in Table 6. Browse production was found to be 95, 247 and 85 kg/ha for the dry season and 236, 310 and 297 kg/ha for the wet season for El-bahoogi, El Idaide and Wad-Shamoon, respectively. The results clearly indicate that the dry biomass production (Browse production) of *Acacia mellifera* (Kitir) trees in El-Idaide (the South part of the Butana rangeland) is higher than browse productivity for the same trees in the center part of Butana (El-Bahoogi) especially in the dry season. The average diameter at the browsing point, tree density and average browsing level are demonstrated in Table 8. The average for *Acacia mellifera* was 3.3 mm while for *Acacia tortilis-ssp raddiana* was 3.05 (mm). Tree density of *Acacia mellifera* (Kitir) in El-Idaidat (South site of Butana) is higher than El-Bahoogi (Center of Butana rangeland).

3.4 Impact of climate change on soil seeds banks

The result of soil seed banks is presented in Table 9. The results indicate that the total number of tree seeds in the El-Bahoogi site was three seeds/m^2, where 33% of these seeds are viable, and 66% are damaged. This number of seeds could not be considered adequate to ensure the natural regeneration of tree cover in the region under normal conditions. Regarding the El-Idaidat site, the soil and seeds number of seed banks/m^2 was four, where 50% of them are viable, and 50% are not viable.

4. Discussion

4.1 Trends of rainfall and temperature

Our study's results showed noticeable variations and decreases in the rainfall amounts and increases in temperature in the last five decades, depending on the analyzed climatic data from the meteorological stations surrounding the Butana region. Many studies in the Butana have shown that there was a change in rainfall rates as a result of global climatic changes. The study carried out by Magboul et al. (2015) and Abdalla (2010) showed that the annual rainfall in the Butana region decreases annually when moving from South to North and East to West. Farouk and Abu Sin (1982) stated that the Butana region is characterized by a high evaporation rate per day in the dry season and high annual rainfall variability. The annual rainfall in the Butana has declined by 15%, and rainfall zones have shifted southwards by 50-100 km. The studies carried out by (Elhag, 2006), and Abdella (2008) proved that there was high variability in rainfall in Butana.

Regarding temperature levels, our study showed that there was a noticeable increase in temperatures throughout Butana as a result of climatic changes. This increase negatively affected the tree/shrub cover and its regional distribution and productivity. The results of our study agreed with (Elagib, 2010; Gil-Alana et al., 2019), who reported that temperature levels increased in Sudan and sub-Saharan Africa. The study by Abdalla (2010) stated that temperature greatly affects evapotranspiration and many authors use the mean monthly temperature to define the length of the rainy season. In Sudan, the increase in the growing season temperature was reported to reduce plant production to some extent (Musa et al., 2021).

Table 6. Main causes of change in trees/shrubs cover in the Butana (according to respondents).

reason to change	count	percentage %
decrease in rainfall	75	50
overgrazing	25	16.7
expansion of rain fed agriculture	2	1.3
all the above mentioned	48	32
total	150	100%

Chi-square (χ^2) = 0.0001.

Table 7. Browse production for *Acacia mellifera* and *Acacia tortilis ssp. raddiana* in the three sites of the study.

site	species	DM production in dry season		DM production in wet season	
		kg/ha	kg /tree	kg/ha	kg /tree
El-bahoogi	*A. mellifera*	95	1.44	236	1.63
El-Idaidat	*A. mellifera*	247	1.80	310	1.82
Wad-Shamoon	*A. tortilis*	85	0.46	297	1.74
P value		0.04*	0.001**	0.38 ns	0.65 ns
SE		25.04	0.12	29.62	0.15

DM = Dry matter, ns, *,** = non-significant and significant at 5 and 1% probability levels, respectively.

Table 8. Average diameter at browsing point and browsing level for *Acacia mellifera* (Kitir) and *Acacia tortilis ssp. radiana* (Sayal) in the three sites of the study.

site name	browse tree/shrub species	diameter at browsing point (mm)	browsing level (mm)	density/ha
El-bahoogi	*Acacia mellifera* (Kitir)	3.30	2.54	130
El-Idaidat	*Acacia mellifera* (Kitir)	3.02	3.00	190
Wad-Shamoon	*Acacia tortilis ssp. radiana* (Sayal)	3.05	2.90	170
SE		0.069	0.070	3.242

Table 9. The viable and damaged seeds of Kittir and sayal trees in the Butana.

site name	tree/shrub species	viable seeds no/m^2	damaged seeds no/m^2	total seeds no/m^2
El-bahoogi	*A.mellifera* (Kitir)	1 (33%)	2 (66%)	3
El-Idaidat	*A.mellifera* (Kitir)	2 (50%)	2 (50%)	4
Wad-Shamoon	*A. tortilisssp.radiana* (Sayal)	3 (50%)	3 (50%)	6

4.2 Farmers' perceptions on climate change on the tree/shrub cover

Our findings obtained from the questionnaire which included 150 respondents stated that climate change had a negative impact on the tree/shrub cover in the Butana rangelands. The impacts were attributed to a decrease in rainfall and an extension of rainfed agriculture and human activities. These findings agreed with the results (Akhtar, 1994; Lazim, 2003), which stated that trees and shrubs covering the Butana rangelands have changed and become inadequate for browsing and grazing. In addition, the natural plant in the Butana rangeland decreased from 46% in 1984 to 26% in 2000 (Ismael, 2009); this decline was due to many factors besides the bad climatic conditions (Sulieman and Ahmed, 2013).

4.3 Effects of climate change on available browse in the Butana rangelands

The study showed differences in browse production in the middle and southern parts of the Butana rangelands. This could be attributed to the variations in tree density between the three sites, which are affected by the amount and variability of rainfall. There is a fact that a better amount of rainfall characterizes South part of the Butana rangeland compared to the other parts of the region. This result agrees closely with Lazim (2003), who assessed the dry matter of *Acacia mellifera* (Kitir) and found that it was 574 kg/ha at rainfall 350 mm. Besides that he reported that rainfall quantity greatly affects browse productivity. In this regard, Abdalla (2010) explained that the amount and distribution of rainfall affect browse and biomass production (Chibinga et al., 2012) of rangeland in the Butana. The decline in rainfall amount was the original power that changed the quantity and vegetation cover in the Butana region of Sudan (Ulieman and Ahmed, 2013). Le Houerou (1984) stated that the relationship between rainfall and biomass production is significant to highly significant relationship, especially in arid and semi-arid areas.

Findings indicated that *Acacia tortilis ssp. raddiana* (Sayal) trees had less browse production compared to *Acacia mellifera* (Kitir) trees especially in the dry season, and this may be due to many factors such as; morphological characteristics of Sayal trees, and this could be due to the fact that the most crown of this species is not within the level of browsing. Selemani et al. (2013) reported that morphological and physiological characteristics could lead to different amounts of biomass production between tree species. The study by (Abdalla et al., 2017) reported a significant positive correlation between yields of browse (total and available browse) and canopy area.

Variation of tree densities of *Acacia melliferia* in the Butana rangelands is attributed to many factors such as rainfall which is clearly varied between central and southern parts of the region. In addition, the low density of this species in the middle part of the region could be due to the low number of seeds found in the ground (seed bank) as a result of drought and intensive grazing during the time of tree seed setting. This result is in line with the study conducted by Eltohami (2016), where they reported that the drought resulting from climate change could affect plant densities and productivity.

4.4 The impact of climate change on soil seed bank

Our study stated that the soil seed bank in the Butana rangelands is very low. The low density of tree/shrubs seeds in the soils in the study sites could be attributed to the decrease in rainfall and variability, an increase in temperatures levels, browsing in times of seeds production, falling of mother trees, and occurrence of wildfires and drought (resulting from direct effects of drought and climate change). In this regard, Fangama (2006) stated that the repeated drought spells, extensive browsing, and cutting off mother trees are responsible for the absence of tree/shrub seeds in the soils.

5. Conclusion

Considering the effects of climatic change on trees/shrubs cover, the present study was conducted to assess the impact of climate change on the browse trees/shrubs and their production in the Butana rangeland. Results of analysis of rainfall data for the fifth meteorological station surrounding the Butana showed a decrease in the trend of monthly and annual rainfall during the period 1961-2013. Temperature analysis indicated a noticeable increase in maximum and minimum rates in all regional meteorological stations since 1985. All interviews confirmed that there was a change in the climate elements (rainfall and temperature), where the rainfall decreased significantly compared to the past decades. Due to the decrease in rainfall patterns and increase in temperature level during the last decade in the Butana rangeland, browse trees/shrubs cover is exposed to negative impacts. This impact has negatively reflected on browse production in the Butana rangeland (El-Idaidat). The low browse production in some parts could be related to the decline of rainfall and increased temperatures in the region over the past years. Moreover, soil seed banks in the Butana rangelands were negatively affected by rainfall decline and upwarding temperatures.

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Ethical Approval
This manuscript does not report on or involve the use of any animal or human data or tissue. So the ethical approval does not applicable.

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Authors Contributions
All authors have contributed equally to prepare the paper.

Availability of Data and Materials
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Conflict of Interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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