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RESEARCH ARTICLE

EFFECTS OF CLIMATE VARIABILITY ON FORAGE PRODUCTION IN SAHELIAN ZONE: CAS BATHA PROVINCE IN CHAD

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ABSTRACT

The effect climate variability on forage production wasstudied in november 2025 in Batha Province in Chad. About 100 questionnaires were distributed to livestock farmers and to collect informations about some climatic parameters in Batha province of Chad. The objectif was to analyse climatic parameters that affect forage production and adaptativestratégies of breeders. The results indicate an increase trend warming accross the sahel, with the hottest months sited between April and May. Littérature reviews reveles that, expected increase in temperature is aroud 2°C by 2050 in the West sahelian Africa. However, annual rainfal fluctuates has been observed over more than three decades in the province of Batha. During these decates, only year 1991, 1999, 2000, 2008 and 2024 registered the higher level of rainfall, with the months of June and august being the months of high precipitation (273,44 mm).The effects of variablity of climatic parametters was the decrease in forage biomass (6,537270 of tons) compared to the dmand (22,289,088 tonsof dry mater) in 2023. Since feeds and nutrients needs of animale and breeders are not satisfayed (famine, 23,5%),they practiceclimatic mobilities (20,5%) southward searching for sustainable forage biomass for survival. This mobility olso creates conflicts between crop farmers and livestock breeders. As a resilient mesures, some periurban breeders make use of crop residus and agroindustrial byproducts as feeds supplments to maintain animal productitivities in the dry season. For sustainable food production, farmers should be organized and trained for proper natural ressourcesmanagement, integrated crops and livestock farming, forage production and banks of forages makingin the dry season in sahelian zones.

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INTRODUCTION

Extensive pastoral production accounts for 25% of the world's land area (Nori et *al*., 2008) and more than 40% of the African continentt's surfce (A, 2013; ECA, 2017). The sahelian countries possess a significant livestock production potential, with an estimated 63 million of cattle, 168 million of small ruminants, and over 6 million of camels (Dicko et *al*., 2006) being a primary source of income, livestock contributes between 30 ant 40% of the Gross agricultural GDP of sahelien countries (Mulumba et *al*., 2008).Chad, a highly landcocked country, alone ahs more than 137664,217 heads of livestock spread over 1284000 km^2 (Alwida, 2022). This sector employs over 82% of the active population and contributes 53% to the rural sector's Gross Domestic Products (MERA, 2018 ; SISAAP, 2024).This economy sector was mobilized to address the debt paiement issue between Chad and Angola involving seventu-five thousand (75000) heads of bovins. That is thirthy-five thousand heads (35000) per quater (Alwida, 2020; Azoutan j. et *al*., 2020). However, climate variability negatively affects animal production, There byexposing sahélian population to food ans nutritional insecurity (Matheron G., 2001; OCHA, 2022). This climat hazard, caracterized by reduced rainfal, poor distribution over time and space, rising temperatures and altering soil conditions that affect crops and forages production, leading to children and pregnant womenmalnutrition in dry season (Béchir and Mopaté, 2015). Transhumance and nomadism that was consideredas resilient solutuons, are nowadays source of fatal conflicts-related challenges between farmers and herders; these herders use agro-industrial by-products and crop residus to complement animal feeds in the dry season (Lawal et *al.*, 20217; Azoutane J. et *al*., 2023). However, some agro-pastoralists and forage sellers stockpiles (natural forage and/or crop residues), which they sell at high prices during period of scarcity to urban and peri-urban livestock farmers (Bencherchali and Houmani, 2017; Azoutane et *al.*, 2019). Moreover, the use of chemical plant protection products like pescticides and herbicides that have broad effects, negatively impact not only the annual biomass of forages (300-1500 kg/ha/year), but also causes public health problème(Westbrooke et al., 2005 ; Azoutane J. et *al*.,2019 ; Valery Mbaigoimem Beral et *al.* 2023) Thus, to maintin Chad's livestock population (137664,217 heads), a deficit of 14,132,008 tons of forage dry maters is noticed (SISAAP., 2024).As such, resilient strategies need to found to improve a socioeconomic conditions of breeder. The aim of this study is to alnalyse ruminants farming conditions during the dry season, despit of the effects of climate variability. More specifically, it was to analys:

- Factors of climat change in sahelian zone ;
- Effets of climate variability on forage production ;

- Adaptation strategies of livestock farmers for sustainable farming in sahelian zones.

MATERALS AND METHODS

Study area: The study was conducted at Ati in the Batha province of Chad Republic (Figure 1) in Auguste 2024. This is located between the 12th an 16th degreees North and covers approxiately 88,800 Km^2 (Béchir and Mopaté, 2015), with a population of 561177 citiwens, representig 4,7% of national population (Mbatbral *et al*., 2019). Geogrphically, Ati is located between 13°12'30''and 13°14'00'' north latitude, and between 18°19'00'' and 18°21'00'' Est longitude, with an area of 21Km^2(Mbatbral *et al*., 2019). The climate is sub-saharan type in the North, and semi-arid in the south, with an average tmperature ranging form 14 to 42°C (Béchir and Mopaté, 2015).

Data collection: Meteorological data from 1982 to 2024 were collected at Ati aérodrome and at the agricultural headquater of Batha for the study of climate variability on forage production in sahelian zone of Chad. The targetd parameters were rainfall amounts and maximum températures. For complementing purpose, the retrospective survey developped by ILRI (International Livestock Research Institute) discribed by Mamadou et *al*., (2017) was conducted with 100 farmers. The ideas collected from herders were based on climate change parameters, the consequences of climate change on life conditins and the resilient strategies developped by socioeconmic developpment actors. Also, littérature review was carried out to analyse forage productionof the Pasture, feeds required by livestock nowadays without ignoring adaptative strategies considered by breeders in response to climate varaibility consequences in the province of Batha.

Statistical analysis

The socioeconomic data of breeders, climate change factors, the effects of climate variability resilience strategies, and perspectives for sustainable management of natural ressources were submited to descriptive analysis using SPSS software version 20.00

RESULTS AND DISCUSSION

Results

Factors of climate variability in sahelian zone: Figure 1 shows the average annual thermal situation of the province of Batha. It shows that the temperature varies throughout the year. The temperature rises form january to may, and fluctuates form june to december.

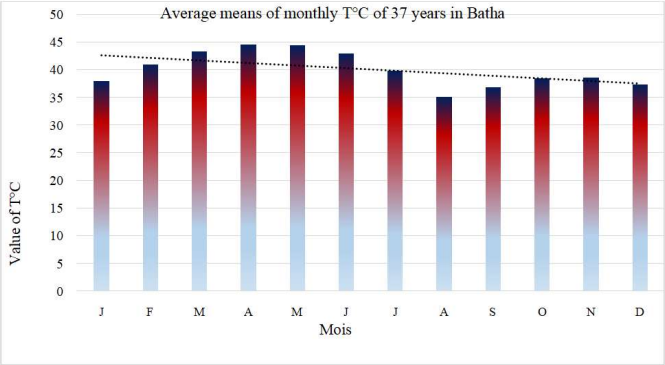


Figure 1. Average monthly rainfal of 37 years in the province of Batha

The average thermal deviations show that, since the 1960s, global warming has been increasing throughout the sahel, and that the hattest months are April and May, with variation in the following months. This situation is illustrated by the elevated temperature from January to May (figure 1) reported by Kaire Marguette in 2013 if Figure 2. Indeed. This author estimates that with climate change, the maximum temperature would increase by 0,5 to 0,9°C, with the maximum of one degree celsius (1°C) in the sahelian region of Africa. This observation confirms CILSS report (20217) that stipulated that an expected increase in temperature is aroud 2°C by the year 2050 in the West sahelian Africa. According to this author, extreme event such as heat waves (90°C) and droughts (66%) are likely to become more intensive and more frequent by the end of centuries.

Annual evolution of rainfal in the province of Batha: Figure 3a hows that annual rainfal fluctuates over more than three decades in the province of Batha. Indeed, the years 1991, 1999, 2000, 2008 and 2024 was the years of high rainfall, with the peak observéd in 2008. From that year onwords, the rainfall level has significantly deceased with the slight increase en 2021. The curve of tendance shows a decrease in rainfall in sahelian zone, with the months of July and augustrecording the higherprecipitation (273,44 mm).

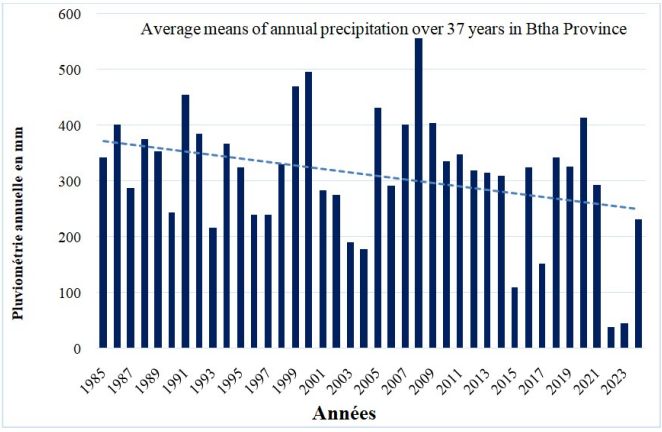
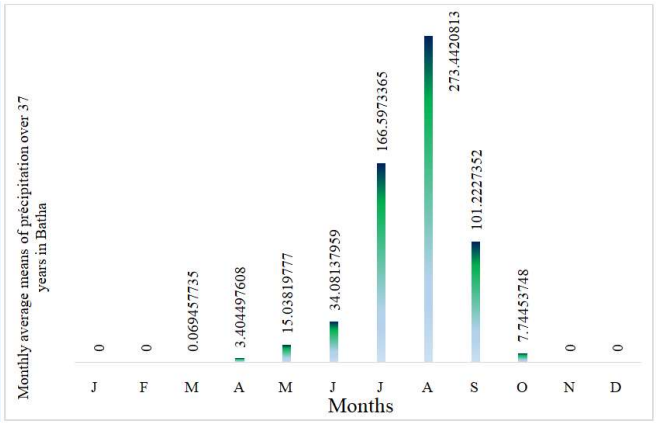


Figure 3a. Annualavrerages of rainfallin in Batha



Source : Ati's Aerodrome, 2024.

Figure 3b.Average monthly means of rainfal in Batha

Effect of climaate change on forage production in the province of Batha: Table 1 attests that demands for foragr biomass is higher in sahelian zone (22,289,088 TDM), with Batha province being the most affected region (14,126,995 TDM). However, the available biomass is estimated to 6,537,270 of TDM, while the estimated damand is about 22,289,088 TDM. Overall climate change induced a deficit of 1,311,122 UBT (*Unité Tropical Bovin*) of forage biomass.Nowadays, the pasture presents a gap of more than 15,751,818 tons of TDM in the dry season these recent yeras. This result is similar to the assertion made by Brigitte T. (2017), who reported a relatively favorable forage production in Westen Chad (Kanem; Bar El Gazal), with biomass coverage bellow the normal level in the Eastern part of the Country.

Consequences of climate variability on living conditions: Table 2 shows that climate change exposes breeders and their livestock to famine (23.5%), climate-induced mobility (20.5%) and low forage biomass production. This is due to the flood (12.5%), drought (5.5%) and the destruction of Fields by herds, therby creating farmers – herders conflicts (11.5%° with serious consequences.

Table 1. Forage avalbility and livestock coverage demand in foroges in sahelian region

Zones/Provinces	Avalable (TDM)	UBT population in 2022	UBT demands in 2023 (TDM)	Ecart (TDM)	Coverage % of forage demand
Barh EL Ghazal	1 613 134	1 781 502	3 028 554	-1 415 420	53%
Batha	3 916 387	8 309 997	14 126 995	-10 210 608	28%
Hadjar Lamis	1 007 749	3 019 729	5 133 539	- 4 125 790	20%
Total Biomass6537270		1311122822289088	- 1575181829%		

Table 2. Consequences of climate variability on living conditions in sahel

Consequences of climate change	Percentage
Littleforagebiomass and crops	17,5
Climate Mobility	20,5
Farmer-Herder conflicts	11,5
Weeds domination on the Field	3,5
Famine	23,5
Flood	12,5
Drought	5,5
Excessif vent	5,5

Table 3. Farmers' adaptation measures to climate variability in the Province of Batha

Paramètres	Stratégies d'adaptation	Pourcentage
	Transhumance	80,50
Alimentation	Pâturage et supplémentation	15,00
(n=100)	Valorisation des résidus des culture et reste de cuisine	4,50
	Choix des races locales (n=100)	95,00
Elevage	Elevage mixte (bovins-Ovins-Caprins) ou dromadaires)	85,00
(n+100)	Elevage mono- espèce	3,50
	Basculade vers l'élevage des dromadaires	11,50
	Vaccination de masse	85,00
Santé (n=100)	Soin des animaux	15,00

Climate variability and farmers' adaptation measures: It appears from table 4 that climate migration (transhumance, 80.5%) seems as the main strategy of survival for herders and their herds. However, grazing associated with supplmentation was also observed (15%) in livestock farms in Batha. Moreover, maintaining local breed as breeders is adopted by most herders (95%). Given the chaotic situation of drought et floods in recent years, livestock formers adopte mixed herd structure (85%) to combat flood shortages taht decimate one groupe species in favor of others. In addition, some farmers seem to be shifting from raising ruminants to raising camels (11.5%) due to losses recorded after the deth of certains species related to climate change, despite signifiacant vaccination coverage (85%) in the region.

DISCUSSION

Effect of thermal variability on the environment: the rise in temperature seems as a major factor of climate change leading to environmental warming, with the month of April and May being the hottest in the sahel region of Chad. This variation aligns with the assertion of Bedoum et *al*. (2013), who estimated that temperature indices show a increase (from 0.5 to 1°C) in the sahelian zone, but to a lesser extent in Chad than in other African countries. According to them, maximum and minimum temperatures follow some trend, with a significant margin for minimum temperature in 2003, which may have reached 2°C over five decades between 1951 and 2010. However, this résult differs from the finding of Mbaiguedem (2012) who stated that the thermal increase from 2002 to 2010 had never been recorded since 1861. This phénomenon could be explained by the migration of isohyets to the south causing a significant spatial expansion of the sahelo-saharian zone, which is not conducive to rainfed crops. According to Lebel et *al*. (2003), this annual southward shift of isohyets leads to a gradual decrease of 20% in the south of sahel to 50% in the north. Indeed, many authors (Maddison, 2006; Majule et *al*., 2008; Lema and Majule, 2009; Abraham et *al*., 2019) argue that the environment is becoming increasingly hot with higher temperatures than usual. This would result in a significant reduction of pastoral ressources and spaces over the decades, exposing the population to food insecurity.

Effect of climate change on food security in Batha: rainfall fluctuations have persisted for several decades (more than 60 years) up to now. The years 1991, 1999, 2000, 2008, and 2024 were those with good rainfall, with the peak observed in 2008. This observation aligns with the authors' assertion that several climatic parameters, either alone or in combination, positively or negatively affect plants throughout their growth (Kana C. E. and Tchekote H., 2023). Thus, seasonality and the uneven distribution of rainfall induced by climate change, result in decreased rainfall in certain monthsand excess in others, as illustrated by the month of July and August, who registererd a total average means of 168.59 mm and 273.44 mm respectively. The climate fluctuations impact not Orly the vegetative cycle of plants, but also food security and nutrition for human and animalspopulations. In fact, energy from solar radiation, atmospheric humidity, and precipitation are essential for photosynthesis. This hypothesis aligns with the assertion of the authors who emphasize that temperature accelerates the biological processes of growth and fruiting (Kana C. E.; Tchekote H., 2023). However, there are threshold values beyond which these effects become detrimental to plant wellbeing (Jing et *al*., 2011). During the different growth stages, exceeding these thresholds produces adverse effects (water stress), leading to transpiration that exceeds water absorption (Vanuytrecht et *al*., 2014; Abraham et *al*., 2019). Indeed, the biological potential of forage plants and the availability of other pastoral resources can be influenced by this phenomenon (Abraham et *al*., 2019), causing no satisfaction of quantitative and qualitative nutrients needs ofanimals. This analysis corroborâteswith the assertion of authors who stated that climate change has a direct effects on crop yields (Djuidje Kamogne *et al*., 2021).

Climate variability and forage production in the Sahel*:* Chad has more than 137,664,217 heads of livestock, of which 34,068,113 Tropical Cattle Units (TCU) are found in the Sahelian zone. The forage requirements of the livestock are estimated at 22,289,088 tons of dry matter (DM), including 14,126,995 DM for Batha. However, the available forage is estimated at 6,537,270 DM. Thus, there is a deficit of 15,751,818 DM, of which 10,210,608 DM is in Central Batha. This observation aligns with the assertion that variability in rainfall and temperature leads to a decrease in forage biomass (Abraham et *al*., 2019). Many authors have also confirmed this

assertion, emphasizing that even though certain forage species exist, their quality and ability to cover the animals' nutritional needs remain critical (Kana C. E.; Tchekote H., 2023).In addition to these climatic desasters, rapid population growth (3.4% per year) accelerates the decrease of pastoral areas (Abraham et *al*., 2019). Indeed, because of limited forage resources and declining animal productivity, herders illegally access to forage ressources in protected areas or bypassing laws protecting these resources; thereby creating a corruption industry and extortion involving state officials from which herders across the Sahel surfer (RBM, 2021). These conflicts, with multiple origins are intensifying due to strong identity-based claims, leading some herders to make use weapons of war.

Consequences of climate variability in the Sahel*:* The main consequences of climate variability are related to the occurrence of famine and climate-induced mobility linked to a descrease in forage production on grazing lands.This analysis aligns with the observation of Salifou M. et *al*. (2024), who estimate that shortening of the rainy season during which rainfall level do not allow plants to complete their growth cycles, leads to forage deficits and the persistence of climate-sensitive endemic diseases (diphtheria, meningitis, respiratory illnesses). Indeed, the high human pressure in the Sahel-Sudanian semi-arid areas seems to have a negative impact on agriculture, livestock, and natural resources, which form the basis of the economy of Sahelian countries (Karimou B.M. et *al*., 2015 and Sivakumar M.V.K. et *al*., 2005). According to several sources (Rawski C., 2020; Sultan B. et *al*., 2020 Soumana B. et *al*., 2021; Salifou M. et *al*., 2024), changes are manifested by a decrease in rainfall, an increase in it variability, and a rise in the frequency of extreme weather events such as droughts and floods leading to a decrease in agricultural yields, an increased risk of famine, and soildegradation. The perception of livestock farmers was focused on the availabilityof forages and uneven distribution of rainfall could be kown as a key indicator that anable them to develop adaptation stratégies against the hazards of climate variability in the Sahel.

Resilience of pastoralists face to climate variability*:* Not only do herders practicetranshumance, but also cross thelocal breeds to have mixed herds to withstand the drought conditions brought by climate change in Sahelia, zone. This analysis confirms the assertion that most herders affected by crises or climatic hazards have been able to build up adaptation strategies; some agro-pastoralists have settled around the urban areas to invest in agriculture, while others continue with transhumantherding as a means of adaptativestrategies, while others become shepherds to rebuild their livestock herd (Billital Marobé Network (RBM), 2021).Indeed, Abraham et al. (2019) reported that migration has been adopted for a century as a strategy for herders to adapt. According to them, mobility reflects the herders' ability to move not only inresponse to constraints, but also as an opportunity for exploration offered by the climate. However, Kgosikoma (2006) believes that this mobility allows animals to make the best use of the uneven spatio-temporal distribution of resources and allows herders to adapt to climate variability. On the other hand, corruption and depopulation of animals, or professional restocking within the herd, anable herders to resist to the adverse effects of climate change (RBM, 2021). Indeed, diversifying species within the herd, extending the duration of transhumance to the deep south, sharing labours within a family, and establishing food banks are all strategies for adaptation or resilience of livestock breeders. As such, herders develop relationships with the host community by seeking mentors to facilitate integration, employing shepherds, developing peri-urban livestock farming, improvising, and trading livestock as a livelihood strategy (RBM, 2021).

CONCLUSION

Climate change negatively affects food security in the Sahel. The rise in temperature and a drasticdecrease in rainfall over these decades lead to evapotranspiration of plants and groundwater. Consequently, the drough and land degradation due to wind erosion, significantly affect soil productivities capaity. However, the annual production of forage biomass from grazing areas no longer meets the food needs of livestock during the dry season in the Sahel. As a result, there is poor performance of animal production coupled with mortality and morbidity among herders and their animals. This situation forces herders to adopt climate migration southward in search of pastures. However, the concentration of transhumantherders in the southern part of the country not only hinders the economic progress of farmers but also disrupts social stability due to the encroachment on fields. Indeed, agro-pastoral conflicts often occureand sometimes resulting in arbitrary arrests. To address food and social insecurity, some peri-urban herders make reserves of natural fodder as feeds supplement in the dry season. For sustainable livestock farming, organizing and raising awareness among herders about proper management of natural resources, along with integrated farming and livestock farming, would better help as an adaption strategie in line with climate variability.On the other hand, the production and creation of forage banks could help in maintaininganimal productivities without harmful fluctuation. As such, we can build asustainableeconomic system of animal production, and fight againt food insecurity in the province of Batha.

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