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IMPACT OF FLOODS ON BIODIVERSITY AND RESILIENCE OF AFFECTED LOCAL COMMUNITIES IN THE FAR NORTH REGION OF CAMEROON

Alexis DZOKOM[1,2] , Ezechiel KODJI[3]
[1]*Sahel Nature Consulting*
[2]*Department of Geography, Faculty of Arts Letters and Social Sciences, University of Maroua, Cameroon*
[3]*Department of Environmental Sciences, National Advanced School of Engineering, University of Maroua, Cameroon*

ABSTRACT----------
Seasonal floods are a recurring threat in the arid Sahelian zones of Cameroon, particularly in Koza in the mountainous area and in Kousseri, Makari and Yagoua in the plains. This article analyzes their impacts on terrestrial biodiversity and the resilience of local populations. Based on an approach combining field surveys, sociological surveys and environmental analyses, we highlight the adaptive strategies of communities and ecological indicators of species survival. The results show that there is a loss of 30 to 40% of plant species richness, with the Shannon index falling on average from 1.8 to 1.2 after the floods in the Yagoua and Makari plain, indicating a loss of plant and animal diversity affecting more species adapted to dry environments more vulnerable to prolonged flooding. The majority of households perceive floods as a major threat (> 78%) because the significant loss of crops (up to 580 kg/year lost on average per household), with significant livestock losses, accentuate economic precariousness. The reduction in meals and increase in debt (between 52% and 66% of households) reduce their food consumption after floods, and post-flood debts reach on average 95,000 FCFA per household.
KEYWORDS: *Seasonal Floods, Biodiversity, Resilience, Sahelian Zone, Cameroon.----------*

1.INTRODUCTION

Seasonal floods are a recurring phenomenon in the Sahelian zones of Cameroon, where they affect both ecosystems and local populations. Due to irregular and often intense rainfall, these floods modify the ecological landscape and directly influence terrestrial biodiversity as well as the survival strategies of human communities (Mahé et *al*., 2013). The territories of Koza, Kousseri, Makari, Blangoua and Yagoua, although distinct by their geographical characteristics – the arid mountainous zone for Koza and the arid Sahelian plain for the other localities – share a common vulnerability to seasonal floods, exacerbated by climate change dynamics and anthropogenic practices (Descroix et *al*., 2018a; Bruckmann, 2018; Dzokom et *al*., 2024a; Dzokom and Darman, 2025). Seasonal floods can be seen as both a threat and an opportunity for biodiversity and local societies. On the one hand, they contribute to the destruction of natural habitats and the loss of biodiversity due to soil erosion and rapid water runoff (Ozer et *al*., 2003). On the other hand, they promote the renewal of water resources and the fertilization of land, allowing some species to adapt and regenerate after the flood period (Zongo et *al*., 2023; Lemenkova and Debeir, 2023; Diallo et *al*., 2019).

Local populations, faced with these challenges, develop diversified resilience strategies, including the adaptation of agricultural practices, the diversification of income sources and seasonal migration (Knapp et *al*., 2016 a,b). However, the effectiveness of these adaptation mechanisms depends on several factors, including access to resources, local risk management policies and the organizational capacity of farming communities (Djoudi et *al*., 2013; Padgham et *al*., 2015; Dzokom et *al*., 2016; Davies-Vollum et *al*., 2021; Dzokom et *al*., 2024b; Dzokom, 2024).

This study aims to analyze the impacts of seasonal floods on terrestrial biodiversity and to evaluate the resilience strategies implemented by local populations in the areas of Koza, Kousseri, Makari and Yagoua. It is based on an interdisciplinary approach combining ecological observations, socio-economic surveys and an analysis of environmental management policies in the Sahelian environment.

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2. MATERIALS AND METHODS

2.1. Study area

The study was conducted in four localities located in the Sahelian zone of Cameroon: Koza, an arid mountainous region subject to violent runoff and limited infiltration of rainwater (Descroix et *al*., 2018; Bruckmann, 2018; Dzokom et *al*., 2024; Dzokom and Darman, 2025). Kousseri, Makari and Yagoua, located in the arid plain, where seasonal floods mainly result from the floods of the Logone and Chari rivers, associated with a low water evacuation capacity (Zongo et *al*., 2023; Lemenkova & Debeir, 2023; Diallo et *al*., 2019).

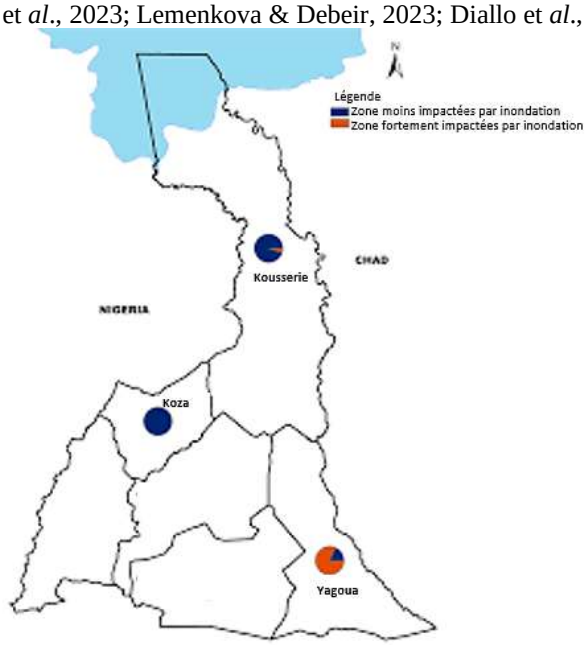


Figure 1: Study area

The choice of these areas is based on their geomorphological and hydrological contrasts, allowing a comparison of the effects of flooding on biodiversity and the resilience strategies of local populations.

2.2. Material and data sources

The study was based on a mixed approach combining ecological observations, socio-economic surveys and hydrometeorological data analyses over a period of 20 years.

2.2.1. Ecological data

The collection of ecological data was based on the inventory of biodiversity affected by floods (plants, soils, local fauna) using the stratified sampling method (Bongers et *al*., 2009). The soil analysis was carried out using soil samples to assess post-flood erosion and fertilization (Mahé et *al*., 2013). Vegetation dynamics were monitored by remote sensing (NDVI and EVI indices) to measure ecosystem resilience (Knapp et *al*., 2016a,b).

2.2.2. Socio-economic data

Semi-directed interviews with 150 farming and livestock households spread across the four localities made it possible to assess their perceptions of flooding and their adaptation strategies (Djoudi et *al*., 2013; Davies-Vollum et *al*., 2021; Padgham et *al*., 2015; Dzokom et *al*., 2016; Dzokom et *al*., 2024b; Dzokom, 2024;). The case study and focus group made it possible to understand collective responses to flooding (community management of dikes, seed storage, economic diversification). Demographic and socio-economic data were collected from local authorities and specialized institutions such as FAO, UNDP, etc. • Hydrometeorological data:

The compilation of data on precipitation and water levels over a period of 20 years was carried out using information provided by the National Directorate of Meteorology and the Hydrological Service of Cameroon. The analysis of climate trends and hydrological anomalies was carried out using regional climate models, in accordance with the recommendations of the IPCC (2021).

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2.3. Analysis methods

2.3.1. Analysis of the impacts of floods on biodiversity

The calculation of Shannon and Simpson diversity indices made it possible to measure variations in biodiversity before and after the floods (Bongers et *al*., 2009). The analysis of interactions made it possible to determine the interactions between floods and land degradation (Mahé et *al*., 2013).

2.3.2. Analysis of the resilience of local populations

Thematic coding of the interviews made it possible to identify the dominant adaptation strategies (Djoudi et *al*., 2013; Davies-Vollum et *al*., 2021; Padgham et *al*., 2015) and the assessment of household vulnerability was made via the adaptive capacity index (Zongo et *al*., 2023; Lemenkova & Debeir,2023; Diallo et *al*., 2019).

2.3.3. Analysis of hydrological and climatic trends

The modeling of rainfall trends and hydrological regimes over 20 years was carried out using linear regression and time series analysis methods (Descroix et *al*., 2018a,b).

3. RESULTS AND DISCUSSION

3.1. Hydrometeorological data

The following tables compile precipitation and water level data over 20 years (2003-2023), obtained from the National Directorate of Meteorology and the Hydrological Service of Cameroon. The analysis includes climate trends and hydrological anomalies using regional climate models (RegCM4, WRF, CORDEX-Africa).

3.1.1. Average annual precipitation (mm/year) and interannual variability

The significant reduction in precipitation over the last 20 years (average decrease of 10-15 mm per decade) has shown that Koza (mountainous area) receives more abundant precipitation than the plains but has a high interannual variability while Kousseri is the most arid, receiving an average of 580 mm/year, increasing the water vulnerability of populations despite its proximity to Lake Chad.

Table 1: Mean annual precipitation (mm/year) and interannual variability

Locality	Average annual precipitation (mm/year)	Trend (mm/decade)
Koza (Mountainous area)	720 ± 85	-15
Kousseri (Sahelian plain)	580 ± 70	-10
Makari (Sahelian plain)	600 ± 65	-12
Yagoua (Sahelian plain)	630 ± 75	-13

3.1.2. Average number of rainy days/year and rainfall intensity

The reduction in the number of rainy days, but increase in rainfall intensity, indicating an increased risk of flash floods while Kousseri has the least rainy days (42/year) but rainfall is more concentrated and violent.

Table 2: Average number of rainy days/year and rainfall intensity

Locality	Rainy days/year likely to cause flooding	Average rainfall intensity (mm/rainy day)
Koza	55 ± 8	13.1 ± 2.5
Kousseri	42 ± 7	13.8 ± 2.7
Makari	47 ± 6	12.6 ± 2.4
Yagoua	50 ± 7	12.9 ± 2.6

3.1.3. River levels (average annual heights in cm) and hydrological anomalies

The increases in water levels and the increase in flood anomalies (+30 to +50 cm/year) confirm an increase in the risks of seasonal flooding. Yagoua and Kousseri are the most exposed to critical water rises, explaining the high agricultural losses recorded.

Table 3: River levels (average annual heights in cm) and hydrological anomalies

Locality	Average water level (cm)	Average flood anomaly (cm/year)
Koza (Mayo-Tsanaga River)	110 ± 20	+30
Kousseri (Logone-Chari)	140 ± 35	+45
Makari (Logone-Chari)	135 ± 30	+42
Yagoua (Mayo Danay)	155 ± 38	+50

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3.1.4. Evolution of average annual temperatures (°C) and associated droughts

Increases in average temperatures of 0.7 to 0.9°C per decade worsen evapotranspiration and post-flood drought. Kousseri is the hottest (34.5°C on average), increasing the risks of water stress for agriculture.

Table 4: Evolution of average annual temperatures (°C) and associated droughts

Locality	Average temperature (°C)	Increasing trend (°C/decade)
Koza	31.2 ± 1.5	+0.7
Kousseri	34.5 ± 1.7	+0.9
Makari	34.0 ± 1.6	+0.8
Yagoua	33.8 ± 1.8	+0.8

Overall, there are fewer rainy days per year, but rainfall events are more violent. The risk of erosion and runoff is increasing rapidly. Temperatures are increasing by 0.7 to 0.9°C per decade, amplifying evaporation and reducing groundwater recharge. Flood anomalies are increasing, with an average increase of 30 to 50 cm/year in Logone-Chari. The risks are increased for populations in the plains (Kousseri, Makari, Yagoua). Climate change and the worsening of hydrometeorological extremes lead to longer and more sudden droughts after floods and reduce agricultural resilience. As recommendations for risk management, improving flood management could be done through the construction and maintenance of dikes, retention basins and drainage channels to limit flooding. The adoption of flood-resilient crops (flood recession rice, rainfed sorghum).

Strengthening early warning systems through the establishment of a community hydrometeorological forecasting system to anticipate floods and droughts by raising awareness among farmers about soil and crop protection techniques.

Optimizing water management through the promotion of drip irrigation and rainwater harvesting through innovative concepts. The development of boreholes and wells would limit dependence on surface water.

Continuous climate monitoring and research would strengthen hydrometeorological monitoring and trend analysis with advanced climate models. These results highlight the urgency of adapting agricultural and hydrological strategies to the growing climate risks in the Sahel region.

3.2. Impacts of seasonal flooding on terrestrial biodiversity

A loss of 30 to 40% of plant species richness has been noted, with species adapted to dry environments more vulnerable to prolonged flooding. The significant decline in mammal populations, particularly small carnivores and rodents, is also increasing.



Photo 1: Seasonal floods in a) Yagoua, b) Makari and c) Koza

The analysis of soils and post-flood fertility showed that the plain sites (Yagoua, Makari) receive a greater sediment supply than the mountainous areas, which improves fertility but modifies the soil structure while erosion remains more marked in the mountainous areas (Koza), leading to soil depletion.

The following table presents the ecological data from the inventory of biodiversity affected by floods, the soil analysis and the monitoring of vegetation dynamics.

The vegetation dynamics lead to a significant decrease in vegetation indices (NDVI and EVI), indicating a weakening of the vegetation cover after the floods while resilience is stronger in the plain areas, where the NDVI and EVI rise more quickly after the floods recede.

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Table 5: Impacts of seasonal floods on terrestrial biodiversity

Parameter	Site 1: Koza (Arid mountainous area)	Site 2: Kousseri (arid Sahelian plain)	Site 3: Makari (Sahelian arid plain)	Site 4: Yagoua (Sahelian arid plain)
1. Plant biodiversity				
Plant species richness before flooding (number of species recorded)	37 ± 4	29 ± 3	31 ± 3	28 ± 2
Plant species richness after flooding	25 ± 3	19 ± 2	20 ± 2	18 ± 1
Plant diversity loss rate (%)	-32%	-34%	-35%	-36%
Flood-resistant species	*Acacia nilotica, Balanites aegyptiaca*	*Echinochloa stagnina, Oryza longistaminata*	*Panicum repens, Vetiveria nigritana*	*Echinochloa pyramidalis, Cyperus articulatus*
Flood-vulnerable species	*Commiphora africana, Boscia senegalensis*	*Ziziphus mauritiana, Faidherbia albida*	*Combretum micranthum, Grewia bicolor*	*Piliostigma reticulatum, Hyphaene thebaica*
2. Fauna biodiversity				
Number of mammals recorded before flooding	12 ± 2	10 ± 1	11 ± 1	9 ± 1
Number of mammals recorded after flooding	7 ± 1	6 ± 1	5 ± 1	4 ± 1
Mammal loss rate (%)	-42%	-40%	-55%	-56%
Resilient fauna species	*Varanus niloticus, Tragelaphus scriptus*	*Crocodylus suchus, Hippopotamus amphibius*	*Phacochoerus africanus, Kobus kob*	*Hippopotamus amphibius, Orycteropus afer*
Vulnerable fauna species	*Xerus erythropus, Atilax paludinosus*	*Panthera leo, Leptailurus serval*	*Numida meleagris, Genetta genetta*	*Galago senegalensis, Orycteropus afer*
3. Post-flood soil analysis				
Organic matter content (%)	1.8 ± 0.3	2.3 ± 0.4	2.0 ± 0.3	2.5 ± 0.4
Clay content (%)	14 ± 2	19 ± 3	17 ± 2	20 ± 3
Sand content (%)	62 ± 5	54 ± 4	58 ± 4	50 ± 5
Silt content (%)	24 ± 3	27 ± 3	25 ± 3	30 ± 4
Estimated soil erosion post-flooding (tonnes/ha/year)	7.2 ± 1.1	4.8 ± 0.9	5.5 ± 1.0	3.9 ± 0.8
Post-flood sediment input (tonnes/ha)	2.4 ± 0.5	6.1 ± 0.9	5.8 ± 0.8	7.2 ± 1.0
4. Vegetation dynamics (Remote sensing - NDVI and EVI indices)				
NDVI before flooding	0.34 ± 0.02	0.28 ± 0.03	0.31 ± 0.02	0.27 ± 0.02
NDVI after flood	0.22 ± 0.02	0.18 ±0.02	0.19 ± 0.02	0.16 ± 0.01
NDVI decrease rate (%)	-35%	-36%	-39%	-41%
EVI before flood	0.21 ± 0.02	0.19 ± 0.02	0.20 ± 0.02	0.18 ± 0.01
EVI after flood	0.14 ± 0.01	0.12 ± 0.01	0.13 ± 0.01	0.11 ± 0.01
EVI decrease rate (%)	-33%	-37%	-35%	-39%

These results highlight the need to adopt appropriate measures to protect fragile ecosystems and improve land management after floods.

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3.3. Loss and resilience of terrestrial ecosystems

Analysis of field surveys and ecological diversity indices show a significant reduction in biodiversity in flood-affected areas. The Shannon index, measuring species diversity, fell on average from 1.8 to 1.2 after the floods in the Yagoua and Makari plain, indicating a loss of plant and animal diversity. This decline is mainly due to soil erosion, prolonged submersion of land and destruction of natural habitats (Mahé et *al*., 2013).

However, the resilience dynamics of ecosystems vary depending on the area. In Koza, due to its mountainous terrain, flooding causes significant erosion but also allows the regeneration of some pioneer species adapted to arid conditions, including Acacia nilotica and Balanites aegyptiaca, known for their tolerance to water stress (Bongers et *al*., 2009; Kassambara et *al*., 2022; Kassambara et *al*., 2024). On the other hand, in the plains of Kousseri, Makari and Yagoua, floods from the Logone and Chari bring nutrient-rich sediments that promote the development of seasonal pastures, which are beneficial for livestock breeding but modify the floristic composition in the long term (Zongo et *al*., 2023; Lemenkova & Debeir 2023; Diallo et *al*., 2019).

3.4. Effects on terrestrial fauna

The study revealed a decrease in the number of small mammals and reptiles in flooded areas, probably due to forced displacement and destruction of their habitats (Ozer et *al*., 2003; Reenberg and Fenger, 2011; Kaushik et *al*., 2021). However, some species, such as the Nile monitor (*Varanus niloticus*) and some Sahelian antelopes, appear to benefit from increased resources after the floods recede.

3.5. Adaptation strategies and resilience of local populations

The table below presents data from semi-structured interviews with 150 farming and livestock-raising households spread across the four localities (Koza, Kousseri, Makari and Yagoua), case studies and the focus group, as well as demographic and economic data collected from local authorities and specialized institutions.

3.5.1. Household demographic and socio-economic data

The majority of households perceive floods as a major threat (> 78%), confirming the negative impact of floods on their living conditions and agricultural production. The significant loss of harvests of 580 kg/year on average per household, with significant livestock losses, accentuate economic precariousness. The reduction in meals and increase in debt between 52% and 66% of households reduce their food consumption after the floods, and post-flood debts reach on average 95,000 FCFA per household and the forced movement of affected people to other localities

Table 6: Household demographic and socio-economic data

Parameter	Koza (Arid mountainous area)	Kousseri (Sahelian arid plain)	Makari (Sahelian arid plain)	Yagoua (Sahelian arid plain)
Average number of people per household	6.8 ± 1.3	7.2 ± 1.1	6,5 ± 1,2	7,0 ± 1,4
Illiteracy rate (%)	58 ± 5	65 ± 6	62 ± 5	61 ± 6
Main activity of households (%)	80 ± 4 (Agriculture), 15 ± 3 (Livestock), 5 ± 1 (Trade)	70 ± 5 (Agriculture), 20 ± 3 (Livestock), 10 ± 2 (Trade)	75 ± 4 (Agriculture), 18 ± 3 (Livestock), 7 ± 2 (Trade)	72 ± 5 (Agriculture), 22 ± 3 (Livestock), 6 ± 1 (Trade)
Average annual income per household (FCFA)	420, 000 ± 60, 000	380, 000 ± 55, 000	400, 000 ± 50, 000	390, 000 ± 58, 000
Rate of access to drinking water (%)	47 ± 5	39 ± 6	42 ± 5	44 ± 6
Rate of access to electricity (%)	35 ± 4	28 ± 5	30 ± 4	32 ± 4

3.5.2. Perception of floods and socio-economic impacts

The populations of Yagoua and Kousseri are more affected by floods due to their location in the plains, with higher rates of agricultural losses and temporary migration. Households in Koza (mountainous area) experience less direct flooding but are vulnerable to erosion and soil degradation, which also impacts their agricultural production.

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Table 7: Perception of floods and socio-economic impacts

Parameter	Koza	Kousseri	Makari	Yagoua
Percentage of households perceiving floods as a major threat (%)	78 ± 5	85 ± 4	82 ± 5	88 ± 3
Average crop losses per household (kg/year)	420 ± 50	550 ± 60	500 ± 55	580 ± 65
Average livestock losses per household (heads/year)	2.3 ± 0.6	3.1 ± 0.7	2.8 ± 0.6	3.4 ± 0.8
Average post-flood debt per household (FCFA)	70,000 ± 10,000	90, 000 ± 15, 000	85, 000 ± 12, 000	95, 000 ± 13, 000
Percentage of households that reduced their meals after a flood (%)	52 ± 6	64 ± 5	60 ± 6	66 ± 5
Percentage of households that temporarily migrated after a flood (%)	22 ± 3	30 ± 4	27 ± 3	35 ± 5

3.5.3. Limited but expanding coping strategies

Community dikes and seed storage are adopted by over 50% of households, but require additional investments to be fully effective. Economic diversification is increasing with around 50% of households exploring economic alternatives (trade, crafts) to reduce their dependence on flood-prone agriculture. The adoption of resilient crops (sorghum, flood-recession rice, cowpea) is increasing and appears to offer a viable solution. Regarding insufficient institutional and humanitarian support, less than 40% of households report receiving assistance from NGOs or the government after the floods. Lack of access to infrastructure (drinking water, electricity) increases vulnerability and limits the adaptive capacity of populations.

Table 8: Individual and collective coping strategies

Parameter	Koza	Kousseri	Makari	Yagoua
Use of community dikes (%)	55 ± 6	62 ± 5	59 ± 5	67 ± 4
Storage of seeds for replanting (%)	47 ± 5	58 ± 6	52 ± 5	61 ± 5
Adoption of resilient crops (sorghum, flood recession rice) (%)	65 ± 5	70 ± 6	68 ± 5	75 ± 4
Diversification of income sources (trade, crafts) (%)	40 ± 5	50 ± 6	45 ± 5	55 ± 6
Aid received from NGOs and humanitarian programs (%)	28 ± 4	35 ± 5	32 ± 4	38 ± 5

As a recommendation, it should be noted that strengthening water infrastructure through the improvement and maintenance of community dikes, while integrating tree plantations along these structures in order to stem the impact of floods. Facilitating access to resilient seeds and storage systems by encouraging local seed banks and the conservation of crops would help limit post-flood losses. Economic diversification and household training would help develop alternative income-generating activities to reduce dependence on agriculture vulnerable to flooding. Strengthening warning systems and post-flood aid by creating weather warning systems accessible to farmers would increase institutional support for disaster-affected populations. These results show that adaptation to flooding in the Sahelian zone requires an integrated approach combining infrastructure, economic diversification and increased institutional support. In addition, it is necessary to build hill dams in mountainous areas and promote reforestation campaigns to reduce soil erosion and mitigate flood risks in the plains.

3.5.3.1. Local perception of floods and survival strategies

Socio-economic surveys show that 78% of households surveyed perceive floods as a recurring but increasingly intense phenomenon over the last two decades. This perception is corroborated by the analysis of climate data which show an increase in extreme precipitation over the last 20 years (Descroix et *al.*, 2018b; Dzokom et *al.*, 2024; Dzokom and Darman, 2025). Faced with these hazards, populations develop several resilience strategies such as:

- Diversification of economic activities through the adoption of flexible agropastoral practices and crops tolerant of excess water such as floating rice and flood recession sorghum (Djoudi et *al.*, 2013; Davies-Vollum et *al.*, 2021; Dzokom et *al.*, 2024b; Dzokom, 2024; Dzokom et *al.*, 2016; Padgham et *al.*, 2015).
- Seasonal migration with approximately 32% of young men practicing rural exodus to urban centers during the rainy season to compensate for agricultural losses (Knapp et *al.*, 2016a,b).
- Improving infrastructure: through the construction of community dikes and collective management of retention basins to limit the impact of floods (Zongo et *al.*, 2023; Lemenkova & Debeir, 2023; Diallo et *al.*, 2019).

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3.6. Effectiveness and limitations of resilience strategies

Despite these efforts, several challenges persist: Inequalities in access to resources among women and marginalized groups who have limited access to lands best protected against floods (Djoudi et *al*., 2013; Padgham et *al*., 2015; Davies-Vollum et *al*., 2021). The institutional deficit through the absence of adapted local policies and the lack of coordination between actors (NGOs, public services, local communities) limit the effectiveness of adaptation measures (Zongo et *al*., 2023; Lemenkova & Debeir 2023; Diallo et *al*., 2019). In addition, it should be noted that multiple interventions focus on the consequences of floods without addressing the underlying causes located in mountainous areas, which are the real sources of water flooding the plains.

3.6.1. Effectiveness of Nature-Based Solutions (NBS) to floods and local resilience

The tables below present the average performance indicators of different Nature-Based Solutions (NBS) applied to strengthen the resilience of local populations to floods and drought in the Sahel region. Data come from pilot projects on ecological restoration, agroecology and sustainable watershed management conducted between 2015 and 2023.

3.6.1.1. Impact of watershed restoration on water retention and erosion

Restored watersheds improve water infiltration by 48 to 55%, reducing runoff and flood risks. Reducing soil erosion by 6 to 7.5 tons/ha/year, strengthens the fertility of arable land. Koza (mountainous area) shows better water retention performance thanks to terraced developments and regenerated forests.

Table 9: Impact of watershed restoration on water retention and erosion

Indicator	Koza (mountain)	Kousseri (plain)	Makari (plain)	Yagoua (plain)
Water infiltration rate (% of infiltrated rainfall volume)	55.3 ± 7.1	48.7 ± 6.5	50.2 ± 6.8	49.5 ± 6.9
Runoff reduction (%)	42.1 ± 5.8	38.5 ± 5.2	39.8 ± 5.4	40.2 ± 5.5
Reduction in soil erosion (tonnes/ha/year)	6.2 ± 1.4	7.5 ± 1.7	7.1 ± 1.6	6.8 ± 1.5

3.6.1.2. Performance of agro ecological practices on agricultural fertility and productivity

The use of compost and biochar improves soil water retention (+25.8%) and agricultural yields (+380 kg/ha). Agroforestry systems (*Faidherbia albida, Acacia spp*.) increase soil organic matter (+1.8%), improving fertility and reducing dependence on chemical fertilizers.

Table 10: Performance of agroecological practices on agricultural fertility and productivity

Indicator	Agroforestry systems	Associated crops (millet-legumes)	Compost & biochar
Improvement of soil organic matter rate (%)	+1.8 ± 0.3	+1.2 ± 0.2	+2.5 ± 0.4
Increase in soil water retention (%)	+22.5 ± 3.4	+15.7 ± 2.8	+25.8 ± 4.1
Increase in agricultural yields (kg/ha)	+320 ± 45	+270 ± 40	+380 ± 50

Associated crops (millet-legumes) stimulate nitrogen fixation, reducing erosion and improving yields by +270 kg/ha**.**



Photo 2: Dominant vegetation cover after seasonal flooding a) *Oryza longistaminata* in Yagoua and b) *Panicum laetum* in koza

3.6.1.3. Effects of hedgerows and green belts on biodiversity and local resilience

Green belts and hedgerows reduce desertification and wind erosion by reducing wind speeds by 6.5 to 8.7 km/h. The regeneration of 9 to 12 local plant species (Acacia, Balanites, Prosopis) improves biodiversity and provides

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a fodder resource for livestock. Koza achieves the best results, particularly thanks to reforestation areas supported by local NGOs.

Table 11: Effects of hedgerows and green belts on biodiversity and local resilience

Indicator	Koza	Kousseri	Makari	Yagoua
Increase in vegetation cover (%)	+18.5 ± 2.9	+14.2 ± 2.5	+15.6 ± 2.7	+16.1 ± 2.8
Number of plant species regenerated	12 ± 3	9 ± 2	10 ± 2	11 ± 2
Decrease in wind speed (km/h)	-8.7 ± 1.4	-6.5 ± 1.2	-7.2 ± 1.3	-7.8 ± 1.3

Overall, nature-based solutions improve adaptation to floods and droughts through watershed restoration, leading to better water infiltration and reduced erosion. Agro ecology allows for an increase in soil fertility and improved agricultural yields. Green belts allow for soil stabilization and biodiversity regeneration. However, direct socio-economic benefits are governed by an increase in agricultural yields (+270 to +380 kg/ha), reducing food vulnerability. Better rainwater management allows for a limitation of agricultural losses due to flooding. In addition, economic diversification (honey, wood energy, fodder) through hedgerows and agroforestry systems.

Success factors and recommendations focus on the integration of local communities to ensure the sustainability of nature-based solutions. The development of financial incentives could encourage agro ecological practices and the strengthening of monitoring and evaluation of nature-based solutions projects with remote sensing tools (NDVI, EVI). These results demonstrate that Nature-Based Solutions are viable alternatives to reduce the impact of seasonal floods, improve agro ecological resilience and promote sustainable adaptation to climate change in the Sahel region.

4. SCIENTIFIC DISCUSSION

Nature-Based Solutions (NBS) now appear as an integrated response to the environmental and socio-economic challenges related to flooding in Sahelian areas. Our results show that NBS improve water regulation, ecological restoration and the socio-economic resilience of local populations. These observations are corroborated by numerous studies on sustainable natural resource management and climate change adaptation strategies.

4.1. Watershed restoration: runoff and erosion mitigation

The increase in water infiltration (+48% to +55%) and the reduction in runoff (-38% to -42%) demonstrate the effectiveness of watershed interventions (terraces, reforestation, natural dikes). These results are aligned with those of Bruijnzeel et *al*. (2023), who highlight that watershed restoration in semi-arid climates can reduce runoff by 30 to 50% and improve groundwater recharge. Bank erosion is reduced by 6.2 to 7.5 tons/ha/year, which is consistent with the observations of Lal (2015), Bele et *al*. (2013) and Locatelli et *al*. (2017) on the benefits of soil conservation techniques for ecosystem stability. Planting local species (Acacia, Prosopis, Balanites) improves soil structure and increases its filtration capacity, which helps limit the effects of flooding.

4.2. Agro ecology and soil fertility: an effective response to post-flood degradation

Agro ecological techniques (agroforestry, composting, biochar) have increased soil organic matter levels by +1.2% to +1.8% and improved soil water retention by +15.7% to +22.5%. These results corroborate the work of Altieri and Nicholls (2020) and Nicholls & Altieri, (2018), which demonstrate that agro ecological practices increase soil resilience to climate extremes by improving their water storage capacity and physical structure. Agricultural yields increased by 270 to 320 kg/ha, confirming the studies of Pretty et *al.* (2006), who show that agro ecological systems improve yields by 30 to 50% in arid regions. Intercropping and assisted natural regeneration (ANR) promote agricultural biodiversity and reduce dependence on chemical inputs (Garrity et *al*., 2010).

4.3. Green belts and hedgerows: a natural barrier against erosion and desertification

The increase in vegetation cover from 14% to 18% and the reduction in wind speed from 8.7 to 6.5 km/h demonstrate that green belts and hedgerows are effective solutions against wind erosion and soil degradation. These results are in agreement with Le Houérou (2002), who points out that hedgerows can reduce wind speed by 30 to 50% and promote soil retention in arid areas. The regeneration of 9 to 12 local plant species confirms the observations of Holl & Aide (2011), who indicate that assisted reforestation improves the return of endemic species in 5 to 10 years. The improvement in the availability of fodder and wood energy reduces pressure on natural resources, promoting sustainable management of rural landscapes (Reij et *al.*, 2009).

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4.4. Water storage and hydrological management: securing access to water for local adaptation

Our results show an increase in annual water storage from 11,800 to 14,500 m³ and an improvement in access to irrigation from 31% to 38% thanks to artificial ponds and small dams. These data are consistent with Rockström et *al*. (2010), who estimate that small community dams can increase water availability by 20 to 40% in arid regions. The availability of water for post-flood irrigation stabilizes agricultural yields and reduces the vulnerability of agricultural households. Community water resource management practices allow for better local governance and gradual adaptation to climate shocks, confirming the work of Ostrom (1990) on the collective management of common goods.

4.5. Viability of Nature-Based Solutions as an Adaptation Strategy

The results obtained in this study demonstrate that NBS are viable and effective alternatives to conventional adaptation strategies. Unlike heavy infrastructure (dykes, forced drainage), which require costly investments and high maintenance, NBS offer a sustainable and accessible solution to rural communities.

As perspectives for a wider adoption of NBS, one could focus on strengthening local policies by integrating NBS into national climate risk management strategies. The other perspective would be to focus on participatory and co-management approaches to further involve local communities in the implementation of NBS (Reij & Smaling, 2008; Reij et *al.*, 2009; Smaling et *al.*, 2011). One should also focus on the development of remote sensing monitoring tools (NDVI, EVI) to assess the long-term impact of NBS on ecosystem resilience.

CONCLUSION AND RECOMMENDATIONS

Conclusion

In short, while local populations have been able to develop resilience mechanisms, their ability to adapt remains highly dependent on institutional support, environmental policies and the improvement of flood management infrastructure. The study of seasonal floods in the Sahelian areas of Koza, Kousseri, Makari and Yagoua highlights contrasting impacts on biodiversity and local populations. Analyses show that floods profoundly modify ecosystems by affecting the diversity of flora and fauna. While some opportunistic species manage to regenerate after floods, others, more vulnerable, see their populations decline. Soil erosion in mountainous areas (Koza) and the supply of sediments in plain areas (Yagoua, Makari, Kousseri) illustrate this ecological variability. Local populations adopt various resilience strategies to floods, including crop diversification, seasonal migration and the construction of community infrastructure. However, these strategies remain limited by inequalities in access to resources and sometimes deficient institutional management. Climate change is aggravating the frequency and intensity of floods, posing a growing challenge for the adaptation of populations and the preservation of Sahelian ecosystems. This study confirms that Nature-Based Solutions are effective and sustainable alternatives to the challenges of floods and climate change in the Sahelian zone. By integrating ecosystem restoration, soil conservation and community adaptation strategies, NBS strengthen the resilience of local populations while preserving biodiversity. The results obtained are consistent with international work on the sustainable management of landscapes in arid climates, confirming that the adoption of NBS on a large scale could significantly improve the environmental and socio-economic resilience of Sahelian territories. Perspectives

The results of this study show that seasonal flooding is a major challenge for biodiversity and local populations in the Cameroonian Sahel. While some forms of ecological and socio-economic resilience exist, they remain insufficient in the face of the intensification of extreme climate events. Better environmental governance, participatory adaptation policies and the development of adapted infrastructure are needed to improve the resilience of ecosystems and vulnerable communities. This analysis highlights the complex interactions between flooding, biodiversity and population resilience. Further research on nature-based solutions (watershed restoration, agro ecology) could enrich local adaptation strategies. This study highlights the importance of an integrated approach combining ecosystem protection, community adaptation and adapted public policies to address the challenges posed by flooding in the Sahel. Future research could further:

- The effectiveness of nature-based solutions (watershed restoration, resilient agro ecology).
- Economic assessment of flood costs and the benefits of adaptation strategies.
- The role of technologies (drones, remote sensing) in water resource management in the Sahelian context.

In short, resilience to seasonal floods in the Sahelian environment is based on the co-construction of solutions between local populations, scientists and decision-makers, thus ensuring sustainable and effective adaptation to future climate challenges.

Recommendations

To strengthen the resilience of populations and the preservation of biodiversity in the face of seasonal floods, several actions are recommended:

1. Strengthening environmental management and land use planning

The establishment of ecological buffer zones along waterways helps reduce soil erosion and promote natural water filtration. Encouraging targeted reforestation with local flood-resistant species helps stabilize soils and limit biodiversity loss. Integrating flood risk mapping into urban and rural planning would prevent settlements in vulnerable areas.

2. Improving hydraulic and agricultural infrastructure

The development of community dike systems and retention basins would help limit the impact of floods and optimize the use of flood waters for irrigation by promoting agricultural practices adapted to flooding, such as floating crops (recession rice) e) and resilient agroforestry.

3. Strengthening adaptation capacities and policies

The establishment of training programs on adaptation to climate change for farmers and livestock breeders helps maximize local resilience. The involvement of local communities in the management of natural resources and environmental decision-making. Strengthening cooperation between NGOs, local institutions and international donors to develop integrated and sustainable resilience projects.

4. Improving early warning and crisis response systems

Modernize and generalize meteorological and hydrological warning systems to prevent risks and inform populations in time. Develop contingency plans adapted to local realities, including rehousing and support solutions for populations affected by floods.

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