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Adaptation Strategies for Sustainable Management of the Impacts of Hydro climatic Risks on Food Security in the Mono River Basin in Benin

Pierre OUASSA[1-2], François Adjéoda MABOULOU[2], Jean SODJI[3], Expédit Wilfrid VISSIN[2]

[1]Laboratory of Climatology and Tropical Ethnoclimatology (CLimET), Department of Geography and Spatial Planning, University of Parakou, BP 123, Parakou, Benin

[2]Pierre PAGNEY Laboratory, Climate, Water, Ecosystem and Development (LACEEDE), University of Abomey-Calavi, Benin

[3]Laboratory of Rural Geography and Agricultural Expertise (LaGREA), FASHS, University of Abomey-Calavi, Benin

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Abstract

Faced with the deleterious impacts of climate change on agrosilvopastoral systems, local communities in the lower Mono River Basin in Benin are developing various endogenous responses. This research evaluates community and institutional adaptation strategies in response to hydro climatic risks that threaten agricultural production and food security in the municipalities of Athiémé, Bopa, Comè, Grand-Popo, and Lokossa. The methodology relies on the analysis of hydroclimatic, agricultural, and socio-economic data (1960–2021), combined with field surveys conducted across 10 sub-districts among 508 households, and supplemented by direct observations and laboratory analyses. The results reveal that flood hazards are characterized by four severity levels (from low to very high), further compounded by droughts that severely destabilize cropping calendars. To cope with these threats, institutional and community measures are deployed: reliance on early warning systems (EWS), partnerships, local committees, adjustment of agricultural practices (ridging, lowland development), local processing, and livelihood coping strategies (migration, reduction of meals, and sale of livestock). In conclusion, optimizing agricultural resilience against food insecurity requires strengthening EWS, adopting climate-smart agriculture, and deploying Nature-based Solutions.

Keywords: Strategy, Early Warning System, Food Insecurity, Agriculture, Mono Basin

1. Introduction

Climate variations and their impacts constitute today one of the most worrying topics for the international scientific community. The uncontrolled growth of greenhouse gas emissions is warming the planet, with the consequences of melting glaciers, increased rainfall, the multiplication of extreme weather events, and the shift of seasons (G. C. Nelson et al., 2009, p.

14). Also, many risks represent particular problems for the least developed countries and vulnerable communities, given their limited capacity to cope with them. People who are socially, economically, culturally, politically, institutionally or otherwise marginalized are particularly vulnerable to climate change (IPCC, 2022, p. 05). The indicators are the increase and multiplication of extreme weather events: droughts, intense rainfall, strong winds, etc. (IPCC, 2022, p. 08). These extreme weather events are proving disastrous for rural communities lacking sustainable solutions to combat these phenomena. The poor or weakened populations are the victims of these disasters (A. Faye, 2022 et al., p. 14).

Under the effect of climate change, the list of pedoclimatic hazards facing sub-Saharan agriculture continues to grow: the occurrences of false starts of the agricultural season and intra-seasonal rainfall breaks, the degradation of soil nutrients, extreme rains, field flooding causing asphyxiation of bottom crops by waterlogging of the soil, the appearance of new diseases or crop pests, and labor losses due to emigration and exodus (B. Sultan et al., 2020, p. 18).

Agricultural systems, and in particular those of the least developed countries, face new and major challenges: producing more to feed a rapidly growing population, especially in sub-Saharan Africa, adapting to climate change and its variability, but also mitigating their contribution to greenhouse gas emissions (B. Sultan, et al., 2020, p. 14). Because, these natural disasters translate into a significant decrease in harvests, water shortages and an aggravation of health crises, with the consequence of increasing food insecurity of the populations, thus threatening the progress made in the fight against poverty (B. Diouf et al., 2014, p. 15).

Benin since the 1960s has been particularly affected by changes in climatic parameters that result in a rainfall deficit and an increase in temperatures (M. Boko, 1988, p. 5; F. Afouda, 1990, p. 4; C. Houndénou, 1999, p. 7; E. Ogouwalé, 2006, p. 11, W. Seydou, 2020, p. 43). Therefore, Benin is facing climate variability and change, and several key business sectors are affected (PANA-Benin, 2022, p. 04). These modifications have the consequences for agriculture of the disturbances of the cultural cycles, the upheaval of the traditional agricultural calendar in force among the peasants (C. Houndénou, 1999, p. 13; E. Ogouwalé, 2006, p. 17). Thus, under the repeated effect of recessions and rainfall disturbances, agricultural yields will be severely affected (H. Afouda, 2016, p. 12). However, agriculture in Benin plays an important social and economic role in the life of the Beninese population (B. Faton, 2013, p. 55). Thus, the risks of food insecurity are high. Variations in the water balance may eventually dangerously jeopardize the closure of the crop cycle and endanger the food and nutritional security of populations (PANA-Benin, 2022, p. 27).

In the basin of the Mono River in Benin, the heavy rainfall recorded in the months of June and July generates the floods of the Mono river with as corollary the floods in the municipalities of Athiémé, Lokossa and Grand-Popo (E. Y. Atiyè, p. 18). Amoussou, (2010), points out that, the quasi-permanent water releases from the Nangbéto dam, have meant that the downstream part of the basin is always wet or the low-water flow is already high (37 m3 / s). However, E. Amoussou

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(2014, p. 26), believes that in many cases, the floodplains and/or watersheds offer excellent technical and economic opportunities to earn an easy living in the lower Mono and Ouémé valleys in Benin. The observations also show that the lower Mono Valley is characterized by an increase in the population, an extension of the cultivation areas, the practice of cultivation techniques that do not respect the environment, increased pressure from pastoral activities and intense agricultural production.

In this climate uncertainty, it happens and cyclically that the floods of the Mono River and its tributaries create floods by putting the entire basin in a state of peninsula; and this especially during the period from July to September (Montin, 2012; E. Y. Atiyè, p. 18). As a result, fertile lands are flooded by rains and overflows of the Mono River and rivers, thus complicating the normal course of agricultural activities. In view of these observations, it is appropriate to conduct a study on hydroclimatic risks in the Benin basin of the Mono River, to reduce the vulnerability of populations to risks related to hydroclimatic variability and to guarantee food security in said basin.

1.1. Area of study

Located in the Gulf of Guinea region in West Africa, the Mono watershed is a cross-border area shared between Benin and Togo, two nations that jointly exploit its water resources and fertile agricultural land. From a topographic point of view, the upper and middle reaches of the basin extend mainly over the Togolese territory, while its lower valley, structured by the major bed of the Mono River and its main tributaries, crosses Benin before emptying into the Atlantic Ocean. Geographically framed between latitudes 06°16' and 09°20' North and longitudes 0°42' and 2°25' East, this basin covers a total area of 27,870 km2. The Benin portion of the basin, at the heart of this research, extends over an area of 2,267 km2. This study area presents a mosaic of geomorphological and hydrographic units, where there is a strong dependence of local populations on agricultural, fisheries and pastoral activities. The socio-economic dynamics of the various municipalities in this sector are deeply dependent on hydroclimatic variability, giving this territory a major scientific relevance for the cross-analysis of hydroclimatic risks and food safety. Fig. 1 illustrates the geographical location of this Beninese portion, highlighting its spatial components and its articulation within the global basin.

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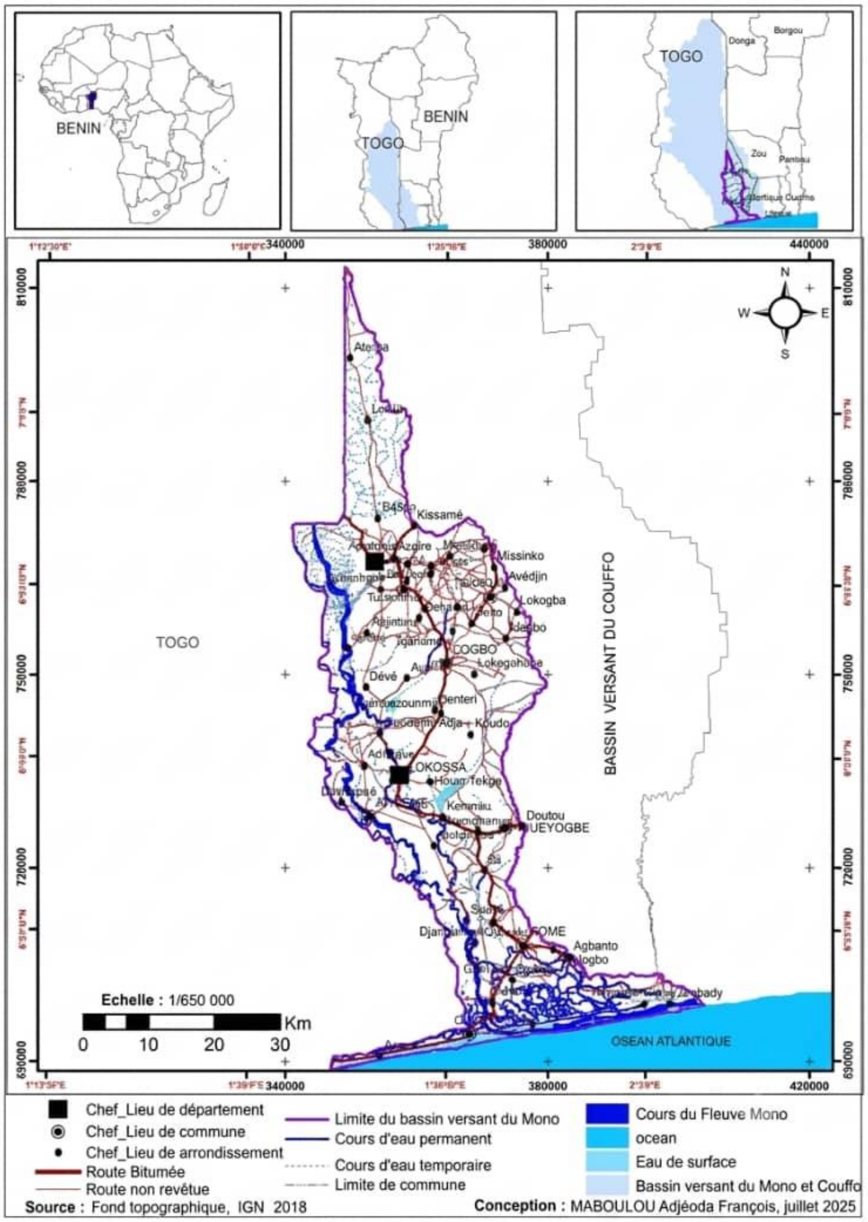

Figure 1: Geographical location of the Beninese portion of the Mono watershed

2. Data and methods

2.1. Data used

In order to precisely analyze the impacts of hydroclimatic risks on agricultural production and food security and to highlight the adaptation strategies developed by communities in the Mono River basin in Benin, several types of data were mobilized. First, climatological data (rainfall, temperatures, humidity, potential evapotranspiration) covering the period 1960 -2021 were

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collected from Météo-Benin. Secondly, the hydrological chronicles relating to the flows and flows of the Mono River have been extracted from the database of the Directorate General for Water (DG-Water). To these physical variables are added the agricultural statistics (1995-2024) obtained from the Directorate of Agricultural Statistics (DSA). Finally, the socio-demographic indicators integrate the results of the General Population and Housing Censuses (RGPH) of 1979, 1992, 2002 and 2013, supplemented by the databases of the National Institute of Statistics and Demography (INStaD). The projection of the population size was made according to the protocol of the geometric hypothesis: Pn =Po (1+a) n with

Pn: projected population;
Po: number of agricultural households in the reference year ;
a: average rate of population growth in the median depression ;
n: difference between the reference year (2002 in the case of this research) and the projection year (2030) for this research.

2.2. Methods used

2.2.1. Field investigation

The sample size was determined according to the formula of SCHWARTZ (2002). Thus, it was calculated with a degree of confidence of 95%, i.e. a margin of error of plus or minus 5%.

$$N = {Z\alpha^2 PQ}/{d^2}$$

With:
N= sample size by rounding
Za = deviation set at 1.96 corresponding to a degree of confidence of 95 %
P = number of households in the district / number of households in the Municipality.
d = margin of error which is equal to 5 %

$$Q = 1 - P$$

By proceeding in this way by municipality, a sampling rate of 30% is applied to the result to determine the exact number of households to be surveyed by district.

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Table I shows the sample used for the field investigations in this work in the Mono basin.

Municipalities	**Districts**	**Villages of investigation**	**No. of households (mother population)***	**No. of people interviewed**	**Percentages%**
Athiémé	Athiémé	Adanlokpe	1 980	24	3,39
		Agbobada	1 453	19	2,69
		Assedji	1 572	22	3,11
	Kpinnou	Bocohoue	1 011	11	1,56
		Don Agbodougbe	1 225	13	1,84
Bopa	Bopa	Bopa Gbedji	1 616	23	3,25
		Masse	1 275	12	1,7
		Sehougbato	1 157	12	1,7
	Possotomè	Akokponawa	1 860	23	3,25
		Possotomè	861	10	1,41
Grand-Popo	Agoué	Agoué I	3 759	27	3,82
		Ayiguinnou	1 971	24	3,39
	Grand-Popo	Ewe Condji	1 751	25	3,54
		Houndjohoundji	1 315	13	1,84
Lokossa	Ouèdèmè	Adjigo Kpodave	1 369	13	1,84
		Agonkanme	1 245	14	1,98
		Ouèdèmè	1 086	11	1,56
	Lokossa	Agnivedji	7 795	32	4,53
		Agonvè	7 593	30	4,24
		Fongba	3 269	26	3,68
		Todoga	853	9	1,27
Comé	Atomè	Agnamé	2 562	22	3,11
		Avégamé	2 799	25	3,54
	Aplahoué	Aplahoué	2 660	23	3,25
		Djikpamè	1 965	20	2,83
		Lokogba	2 683	25	3,54
Total			**1714**	**508**	**71,86**

Source: INStaD 2013 and documentary research 2024

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Table I shows that 508 people were individually interviewed in 05 municipalities, 10 districts and 26 village localities in the Mono basin in Benin. Indeed, the interviewees are at least eighteen (18) years old and sixty (60) years old at most because they are able to provide accurate information on the questions asked to them.

The surveys were conducted using a structured questionnaire. In addition, a (01) "focus group" was carried out by survey village in the public squares chosen by the populations as shown in the photos of the following plate.

1.1

1.2

Plate 1: Focus group in Grand-Popo (1.1) and interview with the producers in Lokossa (1.2)
Shooting: Maboulou, June 2026

The focus groups and direct exchange sessions made it possible to experience the realities of this locality and also favored the confrontation of practices with discourses, the lived experience with the statements of the interviewees. A survey guide has been developed. The techniques used are essentially based on agro-climatological and socio-anthropological approaches, interviewing and direct observation of the terrain using an observation grid respectively in the municipalities of Arhiémé, Bopa, Comé, Grand-Popo and Lokossa.

2.2. Identification of adaptation options

In a first step, the possible adaptation strategies were inventoried according to the impacts of the risks through exchanges with the farmers on the ground supported by the documentation. In Table II (adaptation matrix), a set of measures to be implemented are listed, considered relevant and adequate to deal with the negative effects of floods and droughts in the study area.

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Table II: Adaptation options matrix

Impact matrix		Impacted variables						
		Cultivated areas	Seeds	Semis	cycle of crops	Crop growth	Crop yields	crops Water availability
Climate risks	Rain and river floods							
	Decrease in rainfall totals							
	Dryness/Pockets of dryness							
	Late start of the season							
	Early end of the rains							

According to the FAO (2002, p. 5), the analysis of livelihoods focuses on the peasants and makes it possible to know the means of existence in the community, the peasants who are not able to satisfy their basic needs, the activities and sources of income of the population, the vulnerable groups, the mechanisms regulating the use and control of basic resources. Figure 2 shows the adaptive capacity of farmers.

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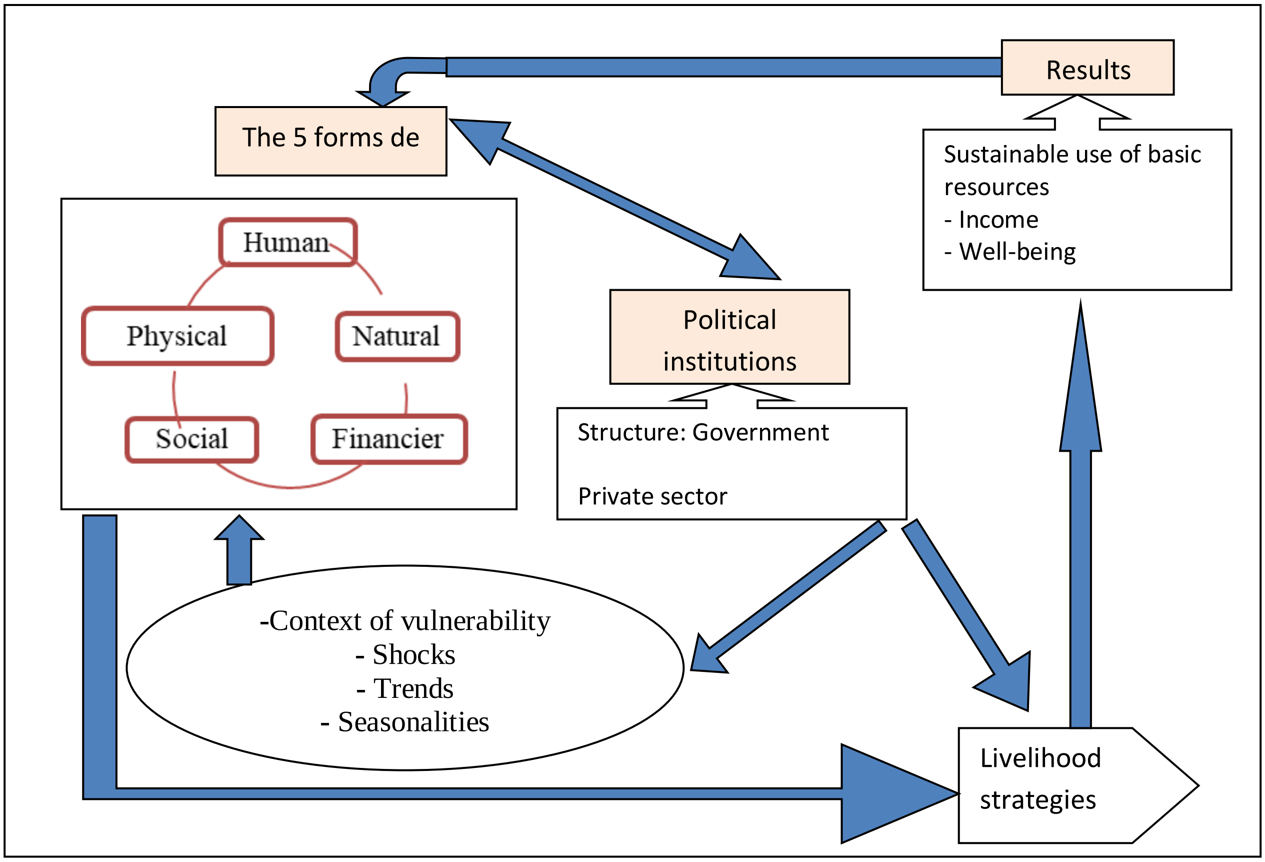

Figure 2: Livelihood framework
Source: Adapted from C. Ashley and D. Carney, 1999 and N. Djenontin, 2010

The livelihood indicators are made up of the :

- human capital: Access to health care, availability of schools and availability of traditional care, security of people and goods and number of able-bodied arms ;
- social capital: Aid from groups, mutual aid, aid from Non-governmental Organizations or the State, rural exodus and family aid ;
- natural capital: Availability of water resources, availability of fertile land, vegetation, progress towards sustainable land management ;
- physical capital which includes: availability of agricultural land, accessibility to agricultural inputs and equipment, accessibility to improved varieties, quality of housing, availability of electricity, existence of markets and schools, availability of road and health infrastructure ;
- financial capital: Income from agricultural work, income from other activities, access to credit, diaspora and product prices.

3. Results and discussion

Several measures are being taken to adapt to climate change by the political and administrative authorities and likewise by the community.

3.1. Preventive institutional measures in the face of hydro climatic risks

The municipal authorities and the populations are already developing several preventive strategies for the harmful effects of hydro climatic variability. Among these, it should be remembered: the institution or the establishment in the municipalities of the Mono basin of a structure whose mission is to manage climate risks, raise awareness and mobilize populations to face them. Also, the public action of NGOs through the development of concrete projects.

3.1.1. Community Alert and Early Warning System

The government, through public policies and national disaster risk reduction strategies, is leading several initiatives for the preparation, prevention and response to disaster risks in high-risk municipalities in Benin.

3.1.1.1. Communal Platforms for Disaster Risk Reduction and Climate Change Adaptation

By DECREE N ° 2011-834 OF DECEMBER 30, 2011 on the creation, composition, attributions and functioning of the national platform for disaster risk reduction Republic and adaptation to climate change in Benin, It is created in the Republic of Benin a National Platform for Disaster Risk Reduction and Adaptation to Climate Change, and Cults. placed under the authority of the Minister of the Interior, Public Security responsible for :

- ❖ Promote the integration of risk prevention and disaster management, in policies, plans and programs for sustainable development and poverty reduction;

To define the strategic orientations and validate the programs established in the field of disaster risk reduction;

To facilitate the mobilization of the resources necessary for the implementation of risk prevention, disaster management, rehabilitation and post-disaster development programs and projects.

The same decree specifies its representation at the Departmental, Communal and Local level with a focus on a Focal Point for Disaster Risk Reduction and Adaptation to Climate Change in charge of corddination.

In its article 6, the National Platform is represented at the Level:

- The Department by the Departmental Disaster Risk Reduction Platform, chaired by the Prefect of the Department;

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- Joint action by the Communal Platform for Disaster Risk Reduction, chaired by the Mayor of the Municipality;
- of the Village or the city district by the Local Platform of the Disaster Risk Reduction Delegate, chaired by the Village Head or the of the district

This decree specifies that their context is identical to that of the National Platform for Disaster Risk Reduction.

In the municipalities of Athiémé, Comé, Bopa, Grand-Popo and Lokossa, this platform is coordinated by a Focal Point who works in synergy with the Mayor, the State and Environmental Affairs Managers as well as technical and financial partners for a good early local monitoring.

3.1.1.2. Meteorological and hydrological alert

The Metrology Agency shares within each municipality, weather alerts from forecasts based on data in collaboration with related agencies such as the ABPC, DG Water, INRHOB, INE and others.
The ballots are shared and presented in the format of the following photo (Photo 1).

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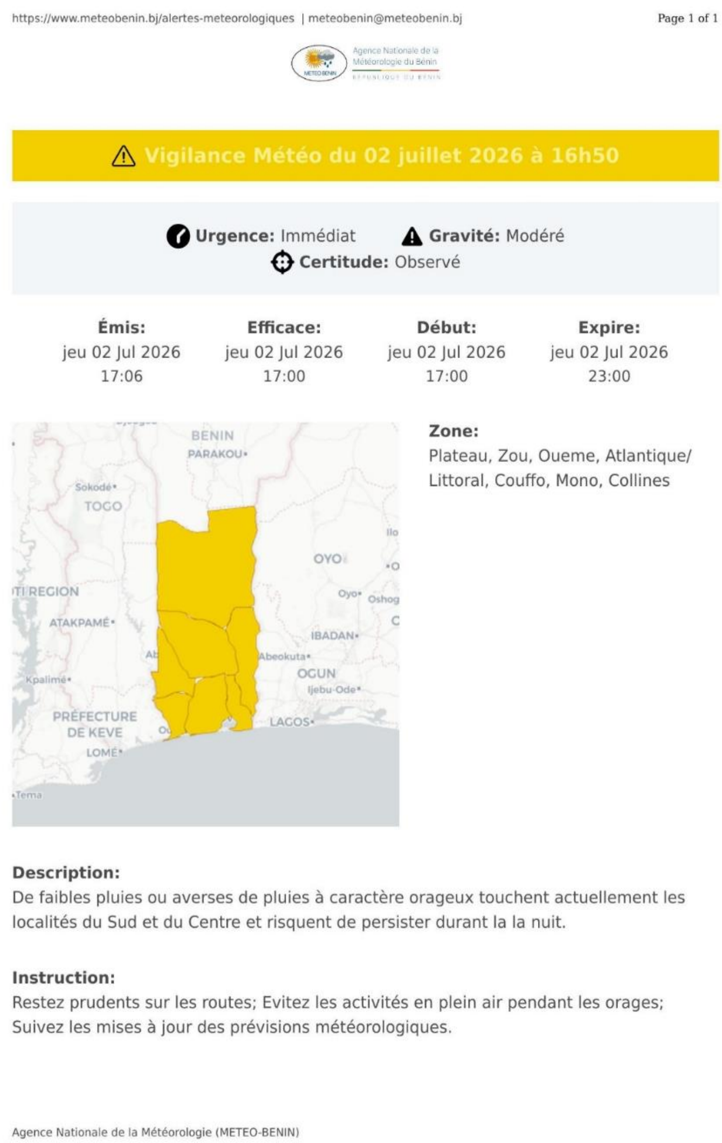

https://www.meteobenin.bj/alertes-meteorologiques | meteobenin@meteobenin.bj Page 1 of 1

Agence Nationale de la Météorologie du Bénin

⚠ Vigilance Météo du 02 juillet 2026 à 16h50

Urgence: Immédiat **Gravité:** Modéré
Certitude: Observé

Émis:	Efficace:	Début:	Expire:
jeu 02 Jul 2026 17:06	jeu 02 Jul 2026 17:00	jeu 02 Jul 2026 17:00	jeu 02 Jul 2026 23:00

Zone:
Plateau, Zou, Oueme, Atlantique/ Littoral, Couffo, Mono, Collines

Description:
De faibles pluies ou averses de pluies à caractère orageux touchent actuellement les localités du Sud et du Centre et risquent de persister durant la la nuit.

Instruction:
Restez prudents sur les routes; Evitez les activités en plein air pendant les orages; Suivez les mises à jour des prévisions météorologiques.

Agence Nationale de la Météorologie (METEO-BENIN)

Photo 1: Benin Weather Alert Bulletin
Source: Benin Weather, July 2026

Photo 1 shows the format of the Benin Weather Alert bulletin often distributed for prevention and community preparedness. The main challenge of this warning measure is the low popularization of weather alerts and community appropriation in local language. Likewise, limnimetric scales are installed for reading and monitoring by the town hall through the coordination and operational management of the competent structures (Photo 2).

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Photo 2: Limnimetric scale on the Grand axis-Popo Comé
Shooting: Maboulou, June 2026

As part of the operational deployment of monitoring devices, several strategic and vulnerable localities in the Mono River basin have been equipped with limnimetric scales intended to monitor water level variations in real time (Photo 2). Field investigations reveal that the monitoring and daily reading of these hydrometric markers are rigorously ensured by community relays, commonly called "scale readers".

This approach, which is based on the direct involvement of local populations, constitutes a hydroclimatic monitoring and citizen science strategy essential for the prevention of flood risks. By measuring the flood line daily, these local actors play the role of sentinels. Their direct observations make it possible to feed the early warning systems (AMPS) and to anticipate the flooding of the spreading plains, thus offering agricultural households the necessary time to secure their harvests and mitigate the critical impacts on food security in the region.

3.1.2. Concrete partnership and investment

The Town Hall, due to its political power and admiration, has established partnerships with technical and financial partners for anticipation, the development of concrete tools on the ground for the benefit of communities, such as the case of the development of a Community Early Warning System (SAP-C) in the Mono basin in Benin with the NGO CREDEL in the municipalities of Grand-Popo, Athiémé and Lokossa with the implementation of 50 beacons for the benefit of communities (Plate 2).

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Plate 2: Beacons implanted in the Mono Basin by CREDEL ONG
Source: Field survey and NGO CREDEL 2025.

These beacons are reinforced concrete devices installed in the Mono basin after several technical and topographic works to identify the points of entry of the water. They constitute today in the Mono basin the first operational alert tool following the alert codes:

Green: Normal Situation
Yellow: Beware the water is coming, vigilance
Orange: The water is here, speed up the harvests and make the arrangements
Red: Danger, evacuate and protect yourself.
Photo 3 shows the awareness panels in the SAP-C in Grand-Popo installed next to the beacons as part of the community early warning systems.

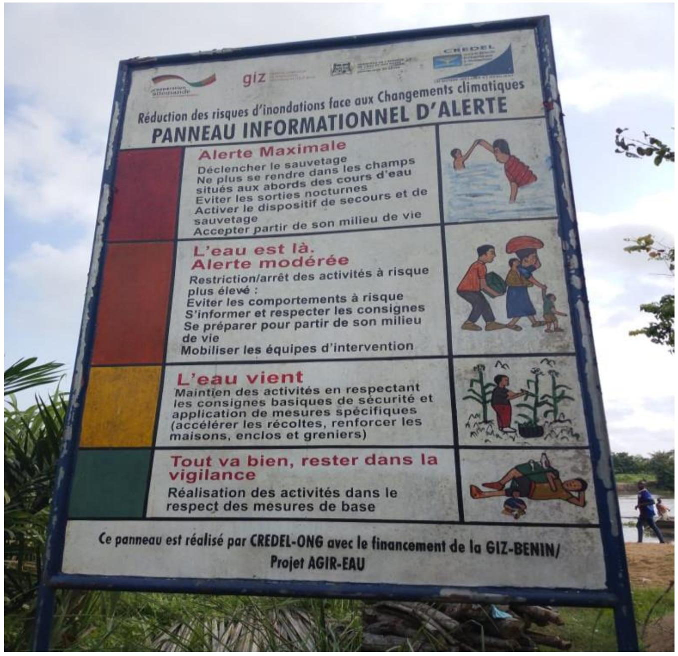

Photo 3: Awareness-raising panel in the SAP-C in Grand-Popo
Shooting: Maboulou, May 2026

The awareness panel in the SAP-C according to the green, yellow, orange and red color codes. These various tools are accompanied by concrete action to raise awareness and train the beneficiary communities (Photo 4).

Photo 4: Community awareness session in the Mono Basin in the SAP-C
Source: CREDEL ONG, July 2025

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Several community awareness sessions in the Mono Basin on the Community Early Warning System (SAP-C) are organized in order to strengthen the community on the reading of the beacons, the preparation and the local response. Also, it is set up scales for measuring the water level

3.2. Community measures to adapt to hydroclimatic risks

Several measures are being developed by farmers to deal with hydroclimatic risks in the Mono basin

3.2.1. Local protection of animals in the face of floods

During seven to eight months of the year, that is to say during the great dry and rainy season, the animals generally wander, graze and feed in nature. From July or / and August, during floods / floods, some breeders build enclosures that last two or three years. Livestock are fed in the final or temporary parks of herbs and panicum leaves for herbivores and food waste, cereal bran and tuber peelings for pigs.

Other breeders, a little more cautious, transhumate their animals on the farmland of the municipalities of the basin when floods are reasonably foreseeable. The unpredictable risks force the local authorities on the spot and those central to the state to respond to the emergency by temporarily relocating the affected populations in classrooms and other health centers or public places available pending the withdrawal of the waters. In these difficult times, many women are reduced to staying at home, no longer being able to engage in the various activities they carry out. The measures to deal with the floods can be summarized as follows:

- sacrifices are made to implore the indulgence of the gods ;
- cleaning (clearing and collecting plants) of the fields to promote the contribution of alluvium and colluvium that fertilize the soil,
- the start of agricultural activities from November or even October on the outskirts of the shallows,
- other producers, on the other hand, start field work as soon as the first rains, that is to say in March, for fear of being surprised by early or unpredictable floods ;
- people or social groups with foresight, contribute by tontines funds, usually small amounts during the floods that they share with each other during the floods in order to reduce financial and food problems in these distressing times of shortage of everything ;
- the reinforcement of the houses in local materials (bench, plank, claie).
- the populations take into account nowadays the magnitude of the floods / floods to build their houses in definitive materials
- the most vulnerable people in the municipalities of the Mono watershed (especially children and the elderly) migrate to neighboring localities and even to Togo to take temporary refuge there. Many young people also take the path of temporary exile to the big cities (Bohicon, Cotonou, Parakou and even neighboring countries such as Togo and Nigeria) to engage in

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other income-generating activities. These activities are those of bricklayers, motorcycle taxi drivers, dock workers, street vendors of various products in detail, etc.

There are also the measures of natural landmarks for the forecast of the next floods called "flood leash'

3.2.2. Valorization of the shallows for resistant crops

In the continuous search for practical adaptation measures in the face of the high hydroclimatic variability, the producers of the Mono basin exploit and strategically enhance the shallows for the benefit of the most resilient crops. This dynamic of local hydro-agricultural development constitutes a major endogenous response to counteract the instability of the rainfall calendar and the recurrence of pockets of drought.

By taking advantage of the residual moisture and the concentration of nutrients in these topographic depressions, agricultural households secure off-season production cycles, in particular for market gardening or short-cycle rice varieties. The reasoned development of these wetlands thus makes it possible to diversify the sources of income, to stabilize the availability of foodstuffs during lean periods and to strengthen the resilience of the operating systems to climate shocks in a sustainable way. The following plate 8 shows the photos of the shallows and resilient crops.

2.1

2.2

Plate 2: Valorization of banana and rice crops
Shooting: Maboulou, June 2026

These adapted practices are cultural practices that make it possible to protect the plots against flooding or to retain water in them during dry periods (digs of earth) or that protect the crops against droughts and the sun (zai or mulch). These practices, sometimes considered as "endogenous adaptation strategies to hydro-climatic extremes" have been observed with farmers supervised and trained as part of development projects or by ATDA agents. Indeed, rice cultivation as well as banana cultivation is one of the activities moderately linked to hydro-climatic extremes. It develops mainly in the form of flooded rice cultivation to meet the internal

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consumption of the country; it is set up on previously unexploited lands because of flooding, with the support of national or international agricultural projects.

3.2.3. Creation of makeshift bridges access to agricultural fields

The bridges of fortunes make it possible to connect two or more geomorphological structures separated by rivers with holes and stagnant waters (Plate 3).

3.1 3.2

Plate 3: Makeshift bridge of passage in the Mono Basin
Shooting: Maboulou, June 2026

The bridges of fortunes of this board constitute a solution of crossing of many producers cut by the high rainwater and the overflow of the streams unable to go to their singing for the early harvest. This strategy often implemented by the communities themselves facilitates access in addition to the use of canoes.

3.2.4. Construction of evacuation channels

Water drainage systems are usually built in the fields. Collection systems built along contour lines are more likely to prevent soil erosion and result in an equal distribution of the collected water over the cultivated area. These systems consist of making sloping drains to bring water to a cultivated land in order to compensate for the water deficit. When the field is flooded, they also serve to evacuate the water as much as possible, for a good yield of the crops. This type of development is based on the availability of surface water and slope systems to facilitate water drainage (Photo 5).

Photo 5: Water drainage system in a field in Comé
Shooting: Maboulou, May 2024

The observation of this photo 9 shows a water discharge channel in a field. Indeed, this agricultural drainage system consists of evacuating the water out of the plots when it is in excess. According to the populations surveyed, during periods of excess rain, land drainage reduces surface runoff and correlatively increases the infiltration of rainwater, but sometimes these drains serve as a place for the passage of water from the river to the fields during flood periods, to prevent water stress at the level of crops, in order to improve agricultural yields. This strategy is practiced by a low rate of respondents. According to 87% of the respondents, this system is poorly developed in the municipalities of the Mono Basin except in the municipality of Comé where it is better developed.

3.2.5 Intensive use of chemicals and Irrigation

The use of chemical inputs and advanced irrigation strategies are a reality in the Mono Basin as shown in the photos on plate 4.

Plate 4: Method of irrigation of the fields in Lokossa (4.1) and use of chemical product in Grand-Popo (4.2)
Shooting: Maboulou, April, 2025

Field investigations have shown in several studies that 60% of the surveyed producers use or resort to the use of chemicals and develop new drainage irrigation methods in the fields.

3.2.6 Local transformation

Farmers process their product locally and market or preserve it. Plate 5 shows the transformation of the red oil to Grand Popo and Lokossa..

Plate 5: Local processing of red oil in Grand Popo (5.1) and Lokossa (5.2)
Shooting: Maboulou, June, 2026

The observations made on the ground show that the producers transform their local products among themselves and seek to conserve locally while waiting for the time of the floods to pass. This strategy often put forward by women prevents the growth of early harvests.

3.3. Global analysis of adaptation strategies in the face of food security from 2016 to 2025

The strategies of monthly adaptations in the face of food security are presented in Figure 3.

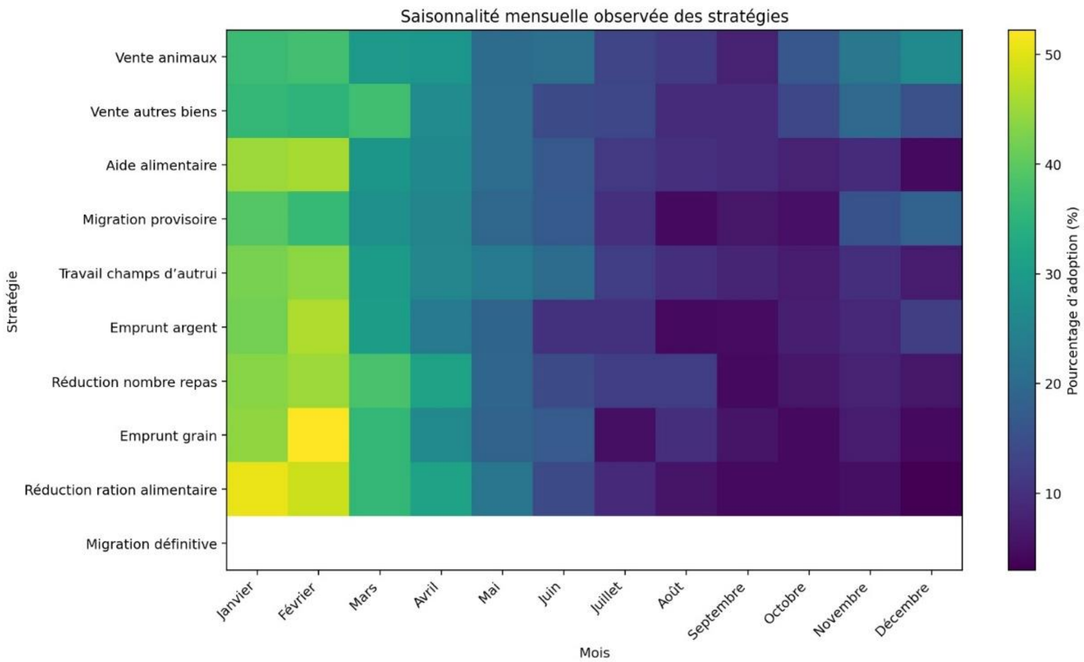

Figure 3: Global analysis of adaptation strategies in the face of food insecurity

This analysis makes it possible to precisely identify the intra-annual dynamics and the vulnerability calendar of agricultural households in the lower Mono River basin. On a global scale, the structure of the matrix reveals a strong seasonality of shocks, characterized by a clear thermal gradient that opposes the first half, extremely critical, to the second half, marked by relative stability or a food lull. The first quarter (January, February, March) concentrates the most alarming adoption rates (yellow to light green shades, oscillating between 40% and more than 50%). This period corresponds structurally to the great dry season and the lean season, when the reserves from previous harvests are rapidly depleted while the opportunities for local agricultural production are at their lowest in the municipalities of Bopa, Comé, Athiémé, Lokossa and Grand-Popo. From May to October, there is a gradual darkening of the heat map (blue to purple hues, falling below the 15% mark), which coincides with the first harvests of the great rainy season which replenish the attics and temporarily stabilize household consumption. Nevertheless, a slight upsurge in strategies is emerging in November and December for certain variables, linked to the preparation of the off-season or to the management of disturbances caused by the late floods of the Mono River.

By breaking down the strategies by typology, we note that direct nutritional adjustments (reduction of the food ration and reduction in the number of meals) are massively activated from the months of January and February, reaching peaks of more than 45-50%. This immediate restriction of caloric intake shows that consumption stress is the first survival lever used by families to spread out the available stocks. Faced with the emergency, financial recourse and solidarity mechanisms are intensifying synchronously: grain borrowing peaks dramatically in

February (bright yellow zone, >50%), indicating an absolute dependence on markets or mutual aid networks to ensure daily subsistence in the heart of the weld. Money borrowing follows a similar trend, remaining very high throughout the first quarter. At the same time, income diversification and decapitalization strategies, such as working in other people's fields and selling goods or animals, show sustained rates (35% to 45%) from January to April. This reflects a strong reallocation of local labor to daily agricultural wage-earners in irrigated areas or low-lying areas that are still exploitable. Finally, temporary migration is also emerging as an early and planned response, with high adoption rates from January and February (around 35-40%) ; agricultural workers temporarily leave the terroirs affected by the seasonal drought to seek additional income in urban or cross-border areas, before returning for the sowing of the great rainy season in May-June. In conclusion, the analyses demonstrate that the vulnerability in the Mono basin is not linear but highly cyclical, which invites local decision-makers and humanitarian organizations to set their interventions (targeted distributions, cash transfers, input supports) specifically on the critical window from January to April in order to maximize their effectiveness.

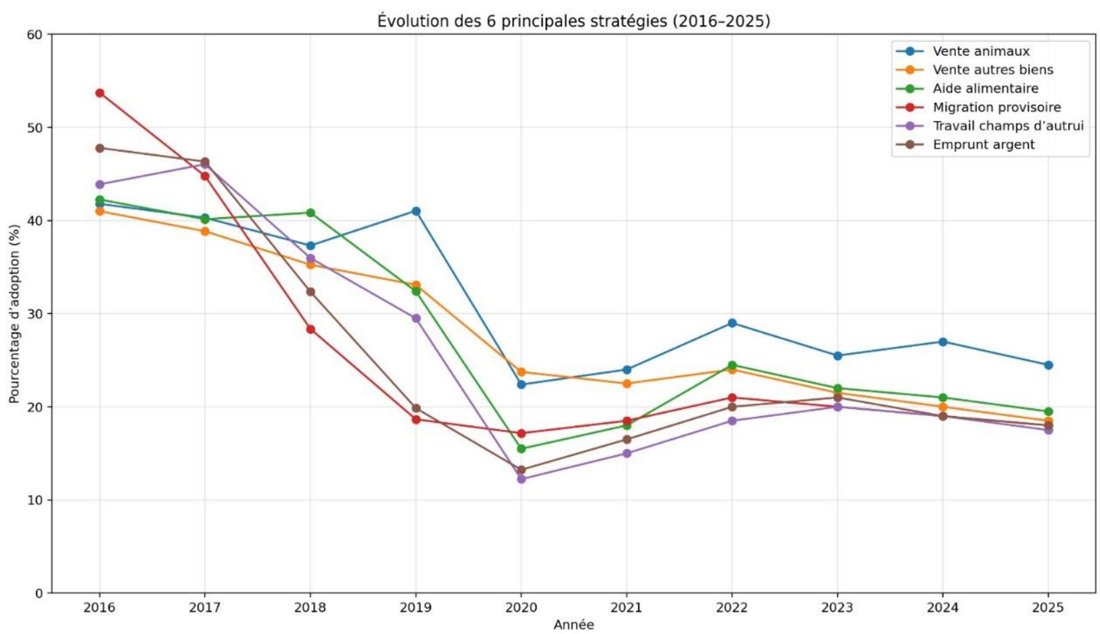

Figure 4 shows the annual evolution of the main food adaptation strategies from 2016 to 2025

Figure 4: Annual evolution of the main food adaptation strategies over the period 2016-2025

The analysis of the figure shows the annual evolution of the six main adaptation strategies, making it possible to precisely follow the quantitative trajectory of the responses adopted by households in the Mono basin from 2016 to 2025. This graph visually confirms the shift from a situation of acute vulnerability to a gradual decrease in the adoption rates of all strategies, materialized by generally descending curves over the entire decade. In 2016, the starting point of the historical series highlights a critical concentration where almost all the indicators are above the 40% mark. Asset erosion strategies lead the chart: "temporary migration" peaks at the top at about 54%, closely followed by "Borrowing money" (about 48%) and "Working in other people's fields" (about 44%). This alignment of initial peaks highlights the intensity of the shock suffered by local communities during this reference year. Between 2016 and 2017, a relative stagnation at high levels is observed, in particular for "Money borrowing" and "Temporary migration" which remain on an unstable plateau around 45 to 46%, reflecting the persistence of the crisis. The major rupture takes place from 2017, characterized by a drastic and continuous decrease in rupture strategies. The "Temporary Migration" collapses by plunging from 45% in 2017 to almost 28% in 2018, then to less than 19% in 2019, almost copying its downward trajectory on that of the "Money Borrowing" (which falls to 32% in 2018 then to 20% in 2019). Conversely, "food Aid" displays a unique asynchronous behavior: it remains stable overall, oscillating around 41% between 2016 and 2018, temporarily becoming the highest curve in 2018 before decreasing in turn. Likewise, the "Sale of animals" shows a particular dynamic by fluctuating between 37% and 41% until 2019, reaffirming its role as a buffer economic lever of first resort for households. The year 2020 marks a terminal inflection point for all the indicators, where almost all the curves converge towards their historically lowest values (between 12% for the work of others and 17% for migration). Finally, over the recent period from 2021 to 2025, a general stabilization phase is observed at low thresholds, oscillating below the 25% mark. Only the "Sale of animals" remains slightly above the other curves (around 25 to 29%), confirming that the decapitalization of small livestock remains the main residual mechanism used by producers in the basin to cushion residual food insecurity.

3.4. Proposal of sustainable adaptation measures to the effects of hydroclimatic risks

3.4.1. Strengthening early warning systems (EWS)

The high recurrence of rainwater (97%) and river floods (95%) requires the transition from a curative crisis management to a culture of anticipation. The strengthening of the SAP in the Mono basin must revolve around the modernization of hydro-meteorological data collection tools (implementation of community beacon in all risk areas and the extension of the alert).

The major innovation lies in the translation of these scientific alerts into local operational indicators, broadcast via community radios and SMS platforms in local languages (Fongbé, Mina, Xwlagbé, Kotafond). This device will allow producers to urgently adjust their harvests and move grain stocks from areas with very high risk to secure community storage infrastructures.

3.4.2. Investment in technology and climate-smart agriculture (CSA)

To break the dependence of households on the unstable rainfall calendar, the introduction of resilient technologies is essential. First of all, this involves the development of vegetable and rice growing perimeters irrigated with micro-doses (drip-drip), powered by solar pumping systems, particularly adapted to the municipalities of Lokossa and Comè to mitigate the impact of pockets of drought (95% of occurrence). Secondly, it is necessary to popularize improved short-cycle seeds tolerant to water stress (early maize, cowpea and vegetable varieties). Finally, the integration of artificial intelligence and digital technologies (drone imaging or satellite vegetation index data) will make it possible to map the health status of crops and optimize the use of water and organic inputs, guaranteeing better food availability.

3.4.3. Nature-Based Solutions (SfN)

Faced with the degradation of ecosystems that accentuates the violence of hazards, the SfN offer sustainable and low-cost responses. In the floodplains of Athiémé and the lake areas of Bopa (Lake Ahémé), it is crucial to restore wetlands and floodplains through reforestation by hydrophilic local species (such as bamboo or Mitragyna inermis), capable of stabilizing the banks and slowing the speed of floodwaters.

In Grand-Popo, priority must be given to the restoration and protection of mangrove ecosystems. These natural barriers not only protect agricultural land from coastal erosion and saline intrusion, but also recreate spawning areas essential to fish fauna, thus consolidating inland fishing as a pillar of local food security.

3.4.4. Community resilience and partnerships

The critical vulnerability of Athiémé (score of 1.33) contrasting with the solidity of Grand-Popo (6.67) or the performance of the Comè and Lokossa markets demonstrates the crucial importance of an integrated approach. It is necessary to structure intercommunal and cross-border agricultural cooperatives to facilitate the pooling of risks.

Strengthening resilience requires the establishment of "Village Solidarity Granaries" and community-managed grain banks to smooth consumption during the critical lean season (January to April). These initiatives must be based on public-private-community partnerships (PPPC) involving the Mono Basin Authority (ABM), municipalities, NGOs and microfinance institutions to co-develop rainfall-indexed crop insurance mechanisms, protecting producers against bankruptcy after a shock.

3.4.5. Valorization of local skills and green entrepreneurship

To avoid recourse to harmful disruptive strategies such as temporary migration or decapitalization (sale of animals), economic diversification via green entrepreneurship is essential. It is necessary to capitalize on endogenous knowledge (community management of shallows, soil conservation practices) by combining them with modern technical skills.

The development of ecological value chains must be encouraged, in particular through :
* The local transformation of cassava and corn into derived products with high added value and long shelf life.
• The large-scale production of compost and bio-pesticides from the water hyacinth (invasive species of Mono and Lake Ahémé), transforming an ecological scourge into an economic opportunity.

* The promotion of resilient aquaculture in floating cages for young people and women from Bopa and Grand-Popo.

3.5. Discussion

Climate change has had major repercussions on the Mono Basin hydrographic complex in Benin (Bopa, Comé, Athiémé, Lokossa and Grand-Popo). The main physical and anthropogenic manifestations induced by these climatic variations are reflected in the drying up of rivers and bodies of water, in particular the Lake Ahémé system and the channels of the mouth (65.42%), the drying up of traditional boreholes and wells (20.32%), the recurrent overflow of the Mono River during flood periods (14.11%), as well as the crowding of populations and livestock around residual water points (9.88%).

Faced with this high variability, the populations of the Mono basin have adopted several adaptation strategies to hydroclimatic risks on the one hand, and traditional methods of preserving water resources on the other hand. Indeed, the management of water by the different socio-cultural groups of the region finds its foundations in their endogenous beliefs. In the traditional local cosmogony, water occupies a prominent place, structured just after earth and air, and before fire (Earth, Air, Water and Fire). Similar results were obtained by R. A. Sedjame (2016, p. 08), which revealed that climatic changes affecting the water resources of the Allada plateau make access to the resource and its governance more complex, insofar as rainfall there has decreased from 9 to 30% over the period 1951-2005.

Therefore, to reduce the vulnerability of their food crops (maize, cassava, market gardening) to hydroclimatic disasters characterized both by the floods in Athiémé and Grand-Popo and by pockets of drought on the Lokossa plateaus, the producers of the basin are developing several preventive measures. By analogy with the farmers of the Benin Pendjari basin who resort to the adoption of short-cycle seeds, transplanting (especially sorghum), the specific arrangement of ridges or the enhancement of the shallows, Mono producers consciously structure their agricultural calendars (P. Ouassa, 2022, p. 216). Such an observation shows that the local population is fully aware of the climatic risks that jeopardize their livelihoods. These observations join those ofA. Toudou et al. (2006, p. 19) in the regions of Maradi, Tahoua and Tillabéri in Niger, as well as L. M. Nassourou et al. (2018, p. 31) in Western Niger. However, faced with changing pedoclimatic and hydrological conditions, beyond these cultural adjustments, some Sahelian communities deploy stony cords or living hedges to increase the average cereal yield by 19%, where the Mono basin relies more on the exploitation of declining crops and the development of banks.

However, as F. I. Ouorou-Barrè points out (2014, p. 225), farmers remain clear-eyed about the fact that their endogenous adaptation practices constitute only empirical experiments, given the high degree of uncertainty surrounding climate forecasts. J. Oloukoï et al. (2019, p. 19) add to this by asserting that these local circumvention strategies are likely, in the long term, to generate

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new pressures on residual natural resources and to further weaken the living conditions of the populations.

This precariousness is confirmed by the dynamics of the short-term responses documented in the study area, where food security is the subject of severe arbitrations. The chronological data (in particular for the critical years 2016-2017) and the intra-annual seasonal profile (particularly from January to April) reveal that the reduction in the number of daily meals and the reduction in food rations are the most critical immediate responses, in concert with the sale of animals which serves as a savings on foot with adoption rates of 67.32% and 56% respectively. The borrowing of silver (42.58%) and the storage or borrowing of grains (38.22%) complete these welding mechanisms. The work of E. Zinzindohoué (2012, pp. 34-35) as well as the AGVSA report (2017, p. 69) corroborate the prevalence of these survival strategies in the study area. Nevertheless, the AGVSA (2017, p. 69) takes the analysis further by indicating that faced with extreme food insecurity, populations come to develop even more severe coping strategies, such as spending a whole day without eating, begging for food or sending dependent family members to take their meals elsewhere.

Conclusion

This research characterizes the extreme hydroclimatic risks in the lower basin of the Mono River in Benin, where rain and river floods coexist (probabilities of 97% and 95%) and recurrent droughts (95%). These hazards seriously disrupt agricultural calendars and accentuate the heterogeneity of food vulnerability, revealing major territorial disparities ranging from a critical situation in Athiémé (score of 1.33) to a solid profile in Grand-Popo (6.67). To cope with this, communities and institutions deploy two main categories of responses. On the one hand, structural strategies translate into the integration of early warning systems, technical partnerships and protective cultural adjustments, such as the making of ridges or the strategic enhancement of the shallows. On the other hand, in times of acute crisis, households resort to immediate livelihood mechanisms: borrowing money, drastically reducing consumption (ration and number of meals) and the sale of animals as living savings. Finally, the persistence of shocks is increasingly structuring temporary migration. Ultimately, securing the basin sustainably requires consolidating early warnings, adopting smart agriculture and deploying Nature-based Solutions.

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