

Article

Vulnerability of Agricultural Households to Human–Wildlife Conflicts around Pendjari Biosphere Reserve in Northern Benin

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Abstract: The Pendjari Biosphere Reserve is one of the protected areas of Benin where biodiversity conservation policies intertwine with the economic development of local populations. It is located in the Atacora region in northern Benin, which has a high prevalence of poverty and food insecurity among households. Agriculture and livestock farming are the primary activities of the local communities in the villages surrounding the reserve. However, wild animals sometimes cause damage to people's fields or livestock. To deal with the damage caused by wild animals, local populations have developed several mitigation measures that may not be effective, leading them into a vulnerable situation. Vulnerability is often associated with the impacts of natural disasters and their management, anticipation, and recovery. In the context of human–wildlife conflict, vulnerability refers to the level of risk farmers face from issues such as crop raiding, livestock depredation, and human injury caused by wildlife, as well as farmers' ability to cope with such damage. To assess the vulnerability of households, we used the Livelihood Vulnerability Index (LVI). Data were collected from July to December 2019 through questionnaires and interviews. We surveyed 320 households to collect data on their socio-demographics, livelihoods, social networks, natural capital, food and water security, and the incidence and severity of human–wildlife conflicts. The results showed that farmers around the Pendjari Biosphere Reserve are highly sensitive to human–wildlife conflicts, with a low adaptive capacity, revealing their vulnerability. More precisely, farmers are vulnerable in terms of major components of the LVI such as water, food, social networks, and livelihoods. Conservation policies are expected to pay more attention to local populations' vulnerability to human–wildlife conflicts in order to improve their tolerance towards wildlife and guarantee the success of conservation efforts.

Keywords: human–wildlife conflicts; livelihood vulnerability index (LVI); conservation; Pendjari Biosphere Reserve; Benin



Citation: Efi, S.; Sogbohossou, E.A.; Magnon, Y.Z.; Hamaide, B.; Tossou, R.C.; Sinsin, B.A. Vulnerability of Agricultural Households to Human–Wildlife Conflicts around Pendjari Biosphere Reserve in Northern Benin. *Land* **2024**, *13*, 1473. <https://doi.org/10.3390/land13091473>

Academic Editor: Francesco Maria Angelici

Received: 4 July 2024

Revised: 25 August 2024

Accepted: 6 September 2024

Published: 11 September 2024



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1. Introduction

Recent conservation policies have mixed conservation with economic development, assuming that conservation programs will provide benefits to local populations living in the surrounding villages of protected areas. Species considered for protection in wildlife conservation scenarios provide socio-economic value and ecosystem services to neighboring populations through, for example, the development of ecotourism, benefitting the local economy. However, in specific areas, they may cause damage to local populations' crops, livestock, and fishing materials, threatening in this way their livelihoods; this paper concentrates on the cost side of wildlife. This issue is called by conservationists Human–Wildlife Conflicts (HWC) [1]. In developing countries where agriculture and livestock farming are important, HWC are more intense, affecting the livelihood and income of people [2].

Although the issue of HWC is widespread, it is particularly severe in Africa, where the majority of the population relies on agriculture, leading to the rapid conversion of natural habitats into farmland [3]. The concept of vulnerability describes a condition or potential condition resulting from the exposure, susceptibility or sensitivity, and adaptive capacity of a system [4]. It was introduced into the literature on HWC in the 1990s by Naughton-Treves [5], who defined it as the extent to which farm households are at risk of damage from wild animals, along with their ability to manage such damage. Two years later, other researchers expanded Naughton-Treves' definition by incorporating both individual and collective aspects of HWC management measures [6]. Vulnerability to HWC refers to the extent to which farmers are at risk of suffering damage caused by wildlife such as crop raiding, livestock depredation, fishing material destruction, human injury, and their ability to cope with such damages. Livelihoods, on the other hand, are the means and way of life that enable individuals to meet their basic minimum needs and those of their families. Livelihoods encompass the resources, skills, and means of support needed for a particular way of life. These are sustainable when individuals can withstand and recover from various crises, such as seasonal, environmental, and economic challenges, while also preserving or improving their resources and capabilities over time without depleting natural resources. Household livelihood vulnerability considers multiple factors, including human, natural, social, financial, and physical dimensions. Agricultural household vulnerability measures how efficiently and sustainably households engage in agricultural activities, taking into account biophysical, social, and institutional factors [7] (Figure 1).

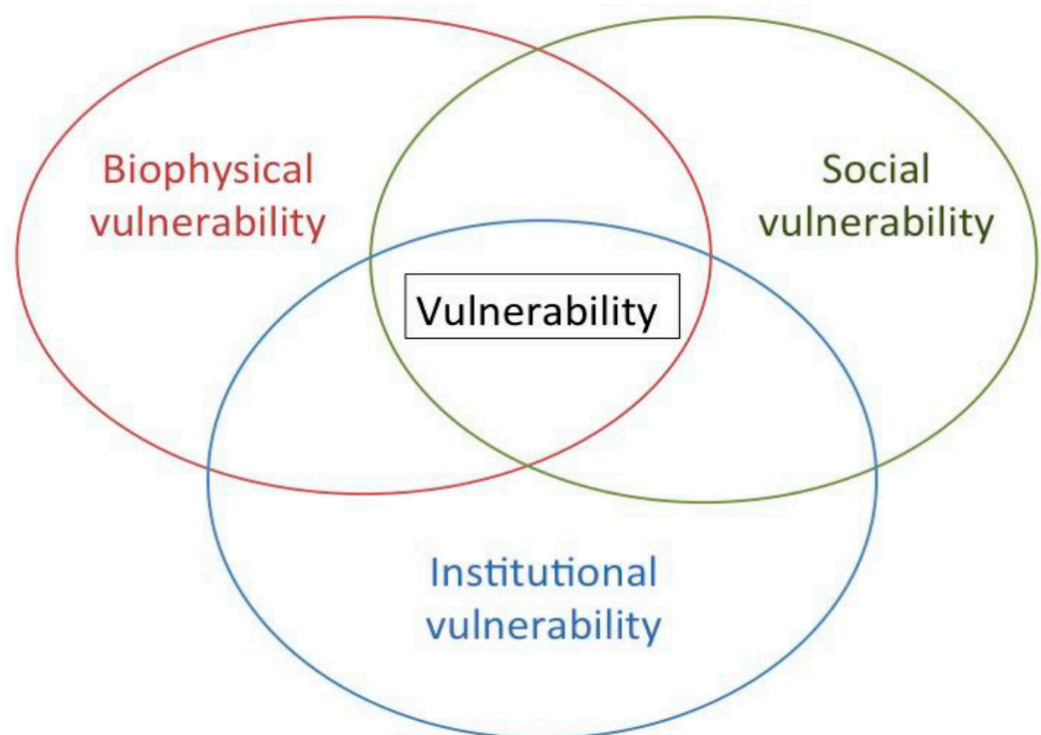


Figure 1. Three-dimensional approach to the concept of vulnerability. Source: [7].

There are various ways to evaluate vulnerability by analyzing the connections between people and their social and physical surroundings [2]. Currently, institutions play a significant role in enhancing the resilience of communities to different sources of vulnerability such as climate change, social disparities, epidemics, HWC around protected areas, and more [8].

The Pendjari Biosphere Reserve (PBR) is located between 10°30' N and 11°30' N, 0°50' E and 2°00' E in the North-West of the Republic of Benin, West Africa. It is part of the W-Arly-Pendjari (WAP) landscape, the largest transboundary protected area in West

Africa. It comprises Pendjari National Park (2,660 km²), which is completely protected from all human activity; the Pendjari hunting zone (1,600 km²) and Konkombri hunting zone (251 km²), where hunting and tourism activities are permitted; and a buffer zone with controlled land-use access for local people (340 km²) that is used for agriculture, grazing, small-scale hunting (that is, the hunting of small and non-protected species for subsistence purpose), fishing, and the collection of non-timber forest products [9]. The geographical relief of the Reserve is particularly marked by the presence of the Atacora mountain range, which limits the availability of land for agricultural activities. The reserve is located in one of the poorest parts of the country. Subsistence agriculture is the main activity of the local communities, with cotton being the main cash crop. Agriculture faces several constraints, including the limited availability of arable land—especially in the Tanguiéta-Batia area, where the population is confined between the Atacora mountain range and the reserve, leading to shorter periods of fallow, soil depletion, erosion, unpredictable and inadequate rainfall, and conflicts between humans and wildlife [10,11] (Figure 2).

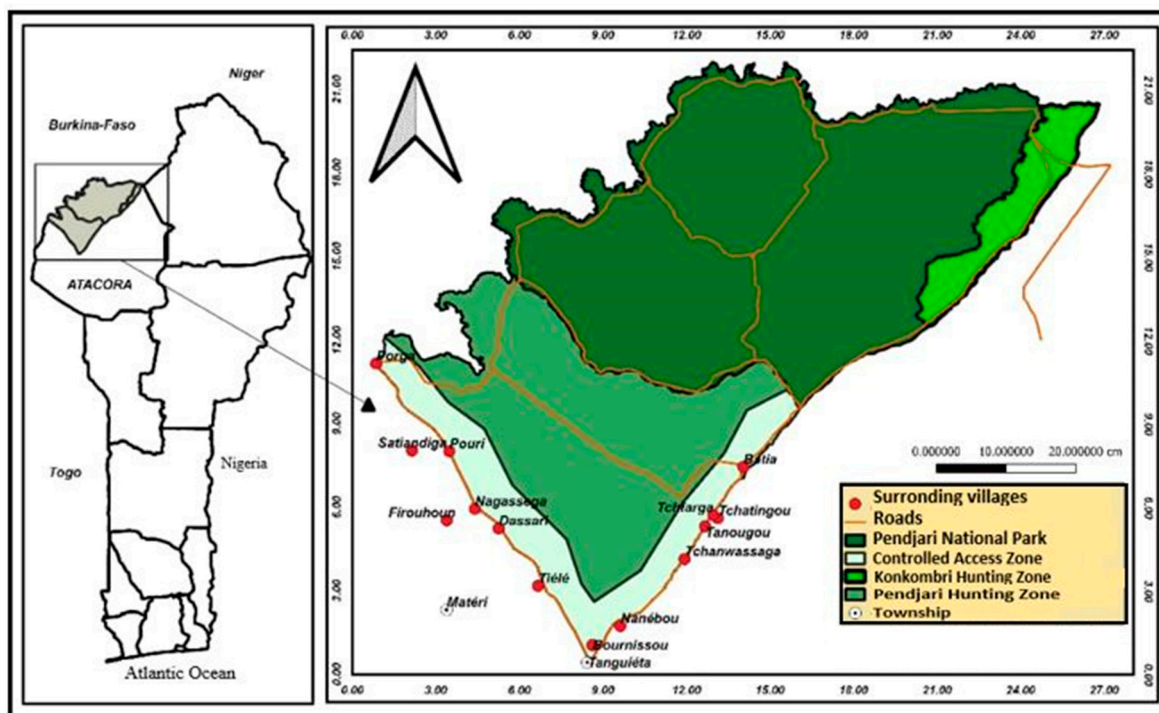


Figure 2. Pendjari Biosphere Reserve and surrounding villages. Source [11].

Human–wildlife conflicts, like in many protected areas, are present around the Pendjari Biosphere Reserve in northern Benin. Three main types of conflicts were observed: crop raiding, livestock predation, and the destruction of fishing materials. The most destroyed crops were maize, cotton, millet, and sorghum, and baboons, elephants, and warthogs were the most important crop raiding species. Concerning livestock predation, pigs and sheep/goats were the most attacked animals, while hyenas and lions were the most important predators reported. Fishing nets and hoop nets were destroyed by crocodiles and hippos in the Pendjari River [11].

Local communities, because of their poverty level, pay a heavy tribute to wildlife. To cope with these damages, local communities have developed several measures such as guarding, fires, and scarecrows. Unfortunately, most of these measures are not effective in preventing fields from damage, and about the quarter of the local populations' production is destroyed every year, causing substantial economic losses for local communities [12].

Rural communities that live near national parks, protected areas, and forests are highly affected by policies that are related to the establishment and management of protected areas. This is because their livelihoods and spiritual needs primarily depend on the resources that

are locally available in forests and their nearby areas [13]. Recent increased surveillance and enforcement policies have reduced pressure on wildlife and increased their population; hence, humans, crops, and livestock in these areas are facing increased threats [14]. HWC is mainly caused by crop loss, livestock predation, and environmental factors that affect the livelihoods of local populations [15,16]. In this paper, we are using the Livelihood Vulnerability Index (LVI) to evaluate the vulnerabilities of agricultural households to HWC in the vicinity of the Pendjari Biosphere Reserve. The LVI, developed by [17], is based on the IPCC's definition of vulnerability. This approach entails considering various factors that reflect the extent of agricultural households' exposure to natural hazards, their sensitivity, and their capacity for adaptation [17].

2. Ethics Statement and Data Collection

2.1. Ethics Statement

The research protocol was approved by the Doctoral School of Agricultural and Water Sciences of the University of Abomey-Calavi (Benin), and all research was conducted according to the ethical guidelines of the school. Every participant in the study was given the option to accept or decline the interview if they felt uncomfortable. Only individuals who provided verbal consent were included in the research. Their personal information was recorded separately to ensure anonymity during analysis and reporting. To ensure informed consent in a primarily orally based culture, we verbally explained the purpose and scope of the research to each participant. The participants were given enough time to reflect on the information and ask questions before giving their consent to participate. They were also informed that participation was voluntary and that they could withdraw at any time [18]. During the interview, each participant was told that their information would not be personally identifiable and that the names of the participants would never be disclosed. Additionally, every participant had the right to decline the interview if they felt uncomfortable, and if they accepted the interview, they could refuse to answer any question they were uncomfortable with. Each interview was conducted individually to ensure complete confidentiality and to avoid having two or more participants together during the interview.

2.2. Data Collection

We drew our sample from villages surrounding the Pendjari Biosphere Reserve. Three main criteria prevailed in the choice of villages to be surveyed: the proximity of the village to the Pendjari Biosphere Reserve, the socio-cultural group, and the extent of animal damage. On the basis of these criteria, 15 villages were chosen in the municipalities of Tanguiéta and Matéri (Figure 2, Table 1).

The size of the sample was determined by a normal approximation of a binomial variable [19]:

$$n = \frac{z^2 p(1-p)}{e^2} \quad (1)$$

where n = sample size; z is equal to 1.96, which is the value of the normal random variable for a probability value of $\alpha = 0.05$; p is the proportion of neighboring households compared to the total number of households in the two municipalities taken into account in the study, namely Tanguiéta and Matéri; e is the margin of error in percentage ($1 \leq e \leq 15$), and we use a 5% error margin. According to [20], the number of neighboring agricultural households is 7611 and the number of agricultural households in the two municipalities is 27,262, i.e., $p = 7611/27,262 = 28\%$. Hence,

$$n = \frac{1.96^2 (0.28 * 0.72)}{0.05^2} = 310 \quad (2)$$

The damages were recorded in activities such as agriculture, livestock, and fishing, carried out in the controlled occupation zone under the supervision of AVIGREF (in French, the Association Villageoise de Gestion des Réserve de Faune), the village units participating

in the management of the reserve. Therefore, we found it important to involve AVIGREF for sampling considerations. With the help of the Pendjari staff, we identified and listed the active members of each AVIGREF and randomly selected the people to be surveyed. A village can have several AVIGREF units depending on its demographic weight. Thus, all of the 15 villages that we have chosen to survey cover 32 AVIGREF units, and our sample size was 310. Dividing the sample size by the number of AVIGREF units, we obtained 9.6875 or 10 individuals to be surveyed per AVIGREF units (Table 1). This explains why 320 individuals were investigated instead of the computed size of 310 persons.

Table 1. Characteristics of research sample showing number of participants per study.

Municipality	Villages	AVIGREF Unit (s)	Participants
Tanguiéta	Tiélé	2	20
	Bourniessou	1	10
	Nanébou	2	20
	Batia	4	40
	Tchafarga	3	30
	Tanongou	3	30
	Tchanwassaga	2	20
	Tchatingou	2	20
Matéri	Dassari	3	30
	Firihoun	2	20
	Nagassega	1	10
	Porga	2	20
	Pouri	3	30
	Satchindiga	1	10
	Tankouari	1	10
Total	15	32	320

Data were collected from 1 July to 30 December 2019 by one of the authors and two field assistants. We used a structured questionnaire to interview each selected informant, typically the person who is responsible for the household, which is often the husband/father. In the absence of an informant, we interviewed the partner (typically, the wife) or his eldest son. Questionnaires were written in French, but interviews were conducted entirely in participants' local languages with the help of a local guide.

3. Data Analysis

Analyzing vulnerability to hazards helps assess how populations are affected and how they adapt to environmental shocks. Many approaches that aim to connect social, natural, and physical sciences [21] depend on three key factors of vulnerability: exposure, sensitivity, and adaptive capacity [22]. Exposure refers to the extent and duration of exposure to hazards. Sensitivity is the degree of impact on an individual or system due to exposure. Finally, adaptive capacity is the ability of an individual or system to resist exposure or recover after a shock [23]. Within this threefold dimension of vulnerability analysis of social–ecological systems, ref. [17] developed an indicator to assess the vulnerability of household livelihoods in the context of climate change in Mozambique. This is the Livelihood Vulnerability Index (LVI). There are various indicators that the LVI uses to evaluate exposure to hazards, as well as the social and economic characteristics that impact a household's ability to adapt. As shown later in this section, the LVI can be computed in two ways: First, it can be a composite index of 7 components. Second, the expression

can be reduced into 3 components based on the IPCC definition of vulnerability: exposure, sensitivity, and adaptive capacity [17]. We chose to use this indicator and adapted it to HWC and the realities of Benin to assess the vulnerability of the residents of the Pendjari Biosphere Reserve. The main reason for this choice is that we consider both climatic disturbances and animal damage as nuisances of the ecological system to the actors of the social system. So, like climate change, we consider HWC as a natural risk.

3.1. Composite Livelihood Vulnerability Index

The calculation of the LVI takes into account 7 components identified by [17], which are: Socio-demographic profile, Household coping strategies, Social network, Health, Food, Water, and Natural hazards (in this case, human–wildlife conflict). In analyzing the seven components, ref. [24] note that they can be categorized into 4 of the 5 capital types of the sustainable livelihoods approach: physical, social, human, and financial capital. Hence, natural capital is not considered in the calculation of the LVI. However, considering the local context of rural areas, the above authors believe that natural capital (access to land, water, and non-timber forest products) is critical in assessing household vulnerability. Therefore, in our study, taking into account the periphery of the Pendjari Biosphere Reserve where the main activities are agriculture and livestock farming, we adopted natural capital as a component of the LVI.

However, we eliminated the component “health” from our calculation. Indeed, this component is taken into account for the calculation of LVI by [17] in the context of climate change with extreme events such as floods and droughts. Floods can be the direct cause of malaria or waterborne diseases. It is therefore relevant to take into account the “Health” component in the assessment of vulnerability to climate change. However, in the case of HWC, which are understood here essentially as crop depredation and livestock predation, “Health” does not appear to be a critical factor. As a matter of fact, according to [25], the relationship of HWC to health relates to either cases of human attack or psychological aspects such as the fear, stress, depression, or trauma of victims of animal attacks. However, cases of human attacks are quite rare around the Pendjari Reserve [11], and psychological aspects are quite difficult to measure and quantify. Overall, considering the specific context of the Pendjari Biosphere Reserve, the health component may not be as critical a factor as in other places, and was therefore omitted for this case-specific LVI. Finally, the components that we retained in the calculation of the LVI of households to HWC around the Pendjari Biosphere Reserve are presented in Table 2¹. The sub-components were chosen on the basis of the literature, consultation with forestry experts, protected area conservationists, social science experts, agricultural experts, and based on our field observations during the exploratory phase of this study.

Table 2. Components and sub-components of LVI.

Components	Sub-Components	Explanation	Source
Socio-demographics (SD)	Percentage of households under the responsibility of a woman	Percentage of households where the primary adult is a woman is calculated. If a male head is absent from the home for more than six months per year, the female is counted as the head of the household.	[17]
	Percentage of households under the responsibility of someone who cannot read or write	Percentage of households where the head of the household has no schooling experience.	[17]
	Dependency ratio	Calculate the dependency ratio by dividing the population under 15 and over 65 years old by the population between 15 and 65 years old.	[17]

Table 2. Cont.

Components	Sub-Components	Explanation	Source
Livelihood Strategies (LS)	Percentage of households that have at least one family member working in a different community		[17]
	Percentage of households that rely entirely on agriculture for their income		[17]
	Average Agricultural Livelihood Diversification Index (range: 0.20–1).	This measures the extent to which farmers are engaged in various activities to diversify their sources of income, and is obtained as follows: 1 divided by (the number of agricultural livelihood activities +1) as reported by a household; e.g., a household that farms, raises animals, and collects natural resources will have a Livelihood Diversification Index = $1/(3 + 1) = 0.25$.	[17]
	Percentage of households engaging in non-agricultural activities		[17]
Natural Capital (NC)	Average size of cultivated land (ha)		[24]
	Percentage of households who report having access to forest products		[24]
Social Networks (SN)	Percentage of households that did not seek help from family or friends in the past year		[17]
	Percentage of households that have not sought assistance from their local government in the last 12 months		[17]
	Percentage of households that did not seek assistance from government institutions during the past 12 months		[17]
	Percentage of households that did not seek help from friends in the past year		
Food (F)	Percentage of households that rely on family farms for their food	Percentage of households that primarily rely on their personal farms as their source of food	[24]
	Average Crop Diversity Index (range: >0–1)	1 divided by (the number of crops grown by a household +1); for example, a household that grows millet, maize, sorghum, and yam will have a Crop Diversity Index = $1/(4 + 1) = 0.20$.	[17]
	Percentage of households that do not save crops	Percentage of households that do not save crops from each harvest.	[24]
Water (W)	Percentage of households that lack a reliable water supply	Percentage of households reporting daily unavailability of a primary water source	[24]
	Percentage of households that have reported conflicts related to water	Percentage of households that have reported being aware of any conflicts related to water	[24]
	Percentage of households that use a natural water source		[17]
Natural hazards (Human-Wildlife Conflicts)	Average crop depredation		[2]
	Average livestock predation		[2]

Source: Adapted from [2,17,24].

The LVI uses a balanced approach by giving each sub-component equal weight when calculating the overall index, despite the fact that each principal component comprises a different number of sub-components [26]. The LVI formula aims to develop an assessment tool that is accessible to a diverse set of users in resource-poor settings. To achieve this, it uses a simple approach of applying equal weights to all principal components. Additionally, to account for the different scales used to measure each subcomponent, a standardized index was created. The equation used for the conversion was adapted from the Human Development Index, specifically the calculation of the life expectancy index. This index is determined by taking the difference between actual life expectancy and a preselected minimum, dividing it by the range of predetermined maximum and minimum life expectancy [17]:

$$IndexS = \frac{S - S_{min}}{S_{max} - S_{min}} \quad (3)$$

where S represents the sub-component per household, and min and max indicate the minimum and maximum values for each sub-component. This yields an index per household that is arithmetically averaged to obtain the overall index for the subcomponent in question. These minimum and maximum values were utilized to standardize the subcomponents or variables, allowing for their integration into the major components of the LVI. After standardization of each subcomponent, the average of each component was calculated according to Equation (4):

$$M = \frac{\sum_{i=1}^n IndexSi}{n} \quad (4)$$

where M = one of the principal components [Socio-demographic Profile (SDP), Livelihood Strategies (LS), Social Networks (SN), Natural Capital (NC), Food (F), Water (W) or Victims of Human-Wildlife Conflicts (HWC)], $IndexSi$ represents the index of the sub-components of each principal component, and n is the number of sub-components in each principal component. Once the values of each of the principal components have been calculated, their average allows us to determine the LVI according to the Equation (5):

$$LVI = \frac{\sum_{i=1}^7 w_{M_i} M_i}{\sum_{i=1}^7 w_{M_i}} \quad (5)$$

which can also be expressed as follows (Equation (6)):

$$LVI = \frac{w_{SDP} SDP + w_{LS} LS + w_{SN} SN + w_{NC} NC + w_F F + w_W W + w_{HWC} HWC}{w_{SDP} + w_{LS} + w_{SN} + w_{NC} + w_F + w_W + w_{HWC}} \quad (6)$$

where the LVI, the livelihood vulnerability index, is equal to the weighted average of the seven principal components. The weights of each principal component, w_{M_i} , are determined by the number of subcomponents that make up each principal component and are included to ensure that all subcomponents contribute equally to the overall LVI [26]. The Livelihood Vulnerability Index value is interpreted as relative values to be compared within the sample area only [3,17,24]. In the case of this work, the LVI was scaled from 0 (least vulnerable) to 0.6 (most vulnerable) [17].

3.2. Livelihood Vulnerability Index by IPCC Framework Approach (LVI-IPCC)

The LVI is also calculated using the three major components of vulnerability according to the definition of IPCC (Intergovernmental Panel on Climate Change), namely, exposure, adaptive capacity, and sensitivity. This approach diverges from the composite LVI in how the seven major components of LVI are combined (Table 3) [17].

Table 3. LVI following IPCC approach.

LVI Major Components	IPCC Definition of Vulnerability
Human–wildlife conflicts	Exposure
Natural Capital	Sensitivity
Food	
Water	
Livelihood Strategies	Adaptability
Socio-demographics	
Social Networks	

Adapted from [17,27,28].

The IPCC-defined contributing factor (CF) is calculated by Equation (7):

$$CF = \frac{\sum_{i=1}^n w_{M_i} M_i}{\sum_{i=1}^n w_{M_i}} \quad (7)$$

where w_M is the weight of each major component, M is the index of a major component, and n is the number of major components in each contributing factor.

After calculating the contributing factors, the LVI-IPCC index is derived using the linear function in Equation (8):

$$LVI-IPCC = (CF_{\text{Exposure}} - CF_{\text{Adaptive Capacity}}) * CF_{\text{Sensitivity}} \quad (8)$$

The calculated value of the LVI-IPCC index ranges from -1 to 1 , i.e., from least to most vulnerable [17,24,27]

4. Results

Table 4 displays the LVI sub-component values, along with the minimum and maximum values, the major components, and the composite LVI. It shows which household characteristics contribute the most to vulnerability in human–wildlife conflicts. The vulnerability indices of the major components ranged from 0.16 to 0.53.

Table 4 reveals that agricultural households living around the Pendjari Biosphere Reserve are globally vulnerable (LVI = 0.40), with a moderate vulnerability (0.26) on the HWC component². Table 5 shows the same trend, with an LVI = $-0.06 \in [-1, 1]$. Based on data from Table 4, the spider diagram of Figure 3 also reveals households' greater vulnerability on the Food (0.5), Water (0.49), Livelihood Strategies (0.37), and Social Network (0.53) components. Indeed, agriculture is the main source of income for the majority (68.44%) of farmers, and 79.1% of them depend solely on the family farm for food, with a low crop diversity index (0.26). The loss of food due to human–wildlife conflicts affects farmers differently depending on whether they have access to old fields or reliable food sources, or if they have other means to feed their families. However, because of HWC, 43% of local populations could not save crops. Livestock that constitute a source of cash income to cover other expenses are also attacked by carnivores. Many heads of households (45.94%) did not attend school; so just a few (31.56%) have access to non-agricultural activities. HWC affects households in terms of food and economic security.

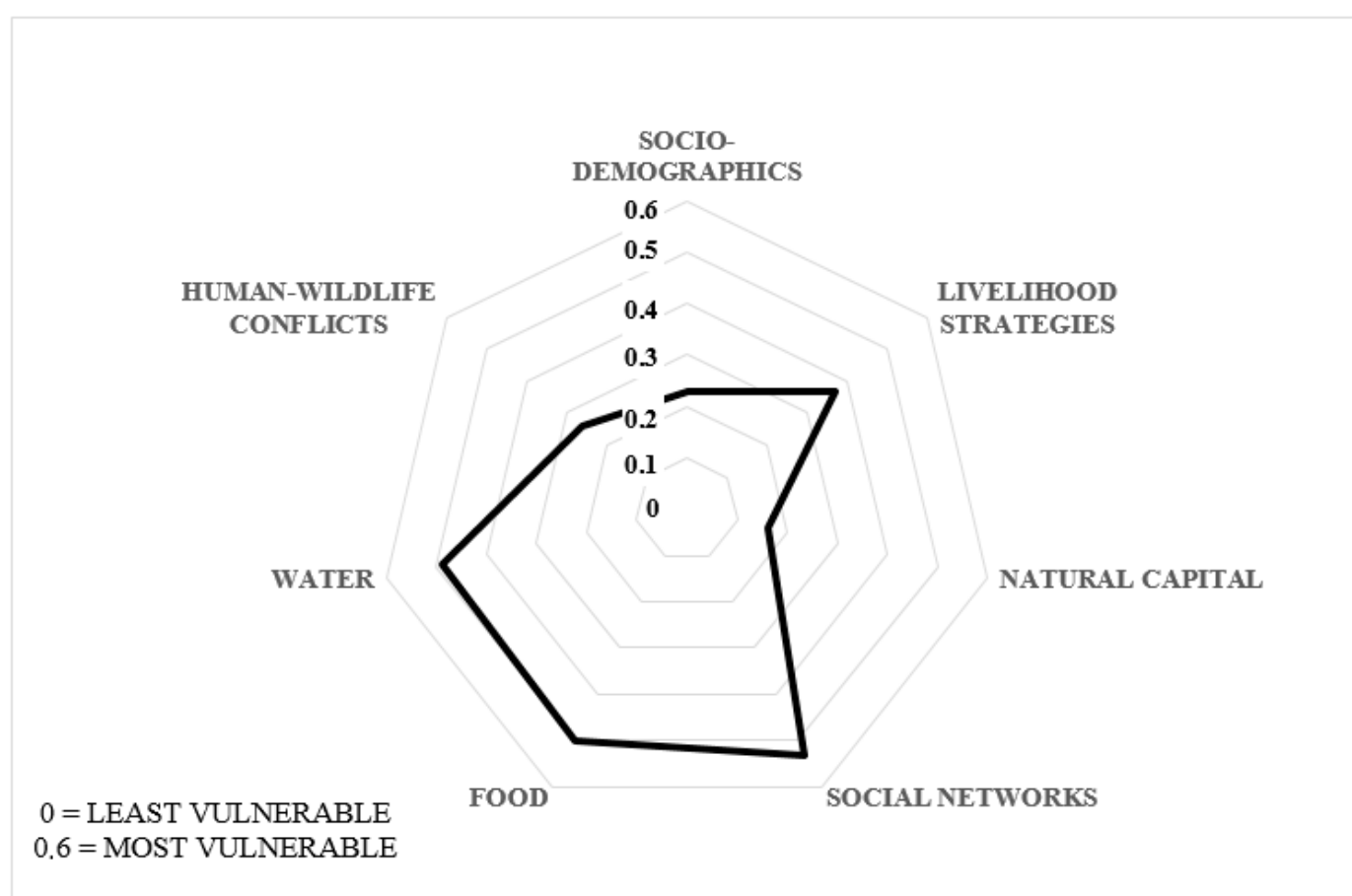
As for the food component, local populations also have a high vulnerability index for the water component. This is because around a third of the population (34.92%) does not have access to a consistent water supply. To compensate for the lack of water, they (37%) resort to natural water sources for domestic needs, livestock feeding, or fishing. Access to these natural water sources is increasingly difficult, which increases the conflicts (70.86%) occurring in the periphery of the Pendjari Biosphere Reserve.

Table 4. Composite Livelihoods Vulnerability Index (LVI).

Components	Sub-Components	Value	Min	Max	Index
Socio-demographics (SD)	Percentage of households under the responsibility of a woman	4.4	0	100	0.04
	Percentage of households under the responsibility of someone who cannot read or write	45.94	0	100	0.46
	Dependency ratio	1.07	0	5.67	0.19
Index SD = 0.23					
Livelihood Strategies (LS)	Percentage of households that have at least one family member working in a different community	4	0	100	0.04
	Percentage of households that rely entirely on agriculture for their income	68.44	0	100	0.68
	Average Agricultural Livelihood Diversification Index	0.36	0.25	0.5	0.44
	Percentage of households engaging in non-agricultural activities	31.56	0	100	0.32
Index LS = 0.37					
Natural Capital (NC)	Average size of cultivated land (ha)	5.7	0.25	35	0.16
	Percentage of households who report having access to forest products				
Index NC = 0.16					
Social Networks (SN)	Percentage of households that did not seek help from family or friends in the past year	4.7	0	100	0.05
	Percentage of households that have not sought assistance from their local government in the last 12 months	96.2	0	100	0.96
	Percentage of households that did not seek assistance from government institutions during the past 12 months	97.8	0	100	0.98
	Percentage of households that did not seek help from friends in the past year	12	0	100	0.12
Index SN = 0.53					
Food (F)	Percentage of households that rely on family farms for their food	79.1	0	100	0.79
	Average Crop Diversity Index (range: >0–1)	0.26	0.17	0.5	0.28
	Percentage of households that do not save crops	43	0	100	0.43
IndexF = 0.50					
Water (W)	Percentage of households that lack a reliable water supply	34.92	0	100	0.35
	Percentage of households that have reported conflicts related to water	70.86	0	100	0.74
	Percentage of households that use a natural water source	37	0	100	0.37
IndexW = 0.49					
Natural hazards (HWC)	Crop depredation costs	1.43	1	3	0.22
	Costs of livestock predation	1.59	1	3	0.29
IndexHWC = 0.26					
LVI = 0.40					

Table 5. Livelihood Vulnerability Index by IPCC Framework Approach.

Contributing Factors	Major Components	Major Components Value	Number of Subcomponents	Values of Contributing Factors	LVI-IPCC Value
Exposure	Human–wildlife conflicts	0.26	1	0.26	−0.06
Sensitivity	Natural Capital	0.16	1	0.45	
	Food	0.5	3		
	Water	0.49	3		
Adaptive Capacity	Livelihood strategies	0.37	4	0.39	
	Socio-demographic profile	0.23	3		
	Social network	0.53	4		

**Figure 3.** Vulnerability spider diagram of the major components of the LVI. Source: Authors' construction.

To reduce the impact of HWC, households have developed some livelihood strategies, mainly agricultural diversification, non-agricultural activities, or turning to their social network for help. The greater vulnerability index of these components reveals the low adaptive capacity of households to manage the HWC around the Pendjari Biosphere Reserve.

5. Discussion

The aim of this study was to assess the vulnerability of agricultural households to HWC around the Pendjari Biosphere Reserve in Northern Benin. The Livelihood Vulnerability Index was used to calculate the overall LVI of the farming households in the area. The results indicate that the households were globally vulnerable (with a LVI of 0.40) and

moderately vulnerable to HWC (with a LVI of 0.26). Specifically, the findings indicated that households were more vulnerable in terms of major components such as water, food, social networks, and livelihood strategies. In addition to the Composite Livelihood Vulnerability Index, we considered the IPCC approach (Table 5) in the assessment of the vulnerability of the households to point out the aspects of exposure, sensitivity and adaptive capacity (Figure 4). According to the IPCC approach, the four most vulnerable components corresponded to households' Sensitivity (Food and Water) and Adaptive Capacity (Livelihood Strategies and Social Network) to HWC. This means that households are sensitive to HWC impacts with a low adaptive capacity, as detailed in the next two sections.

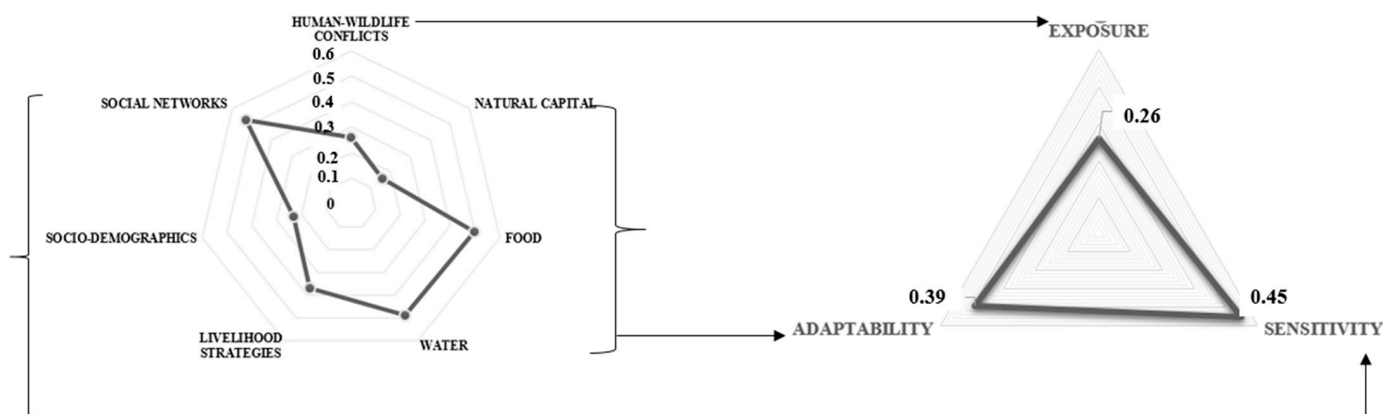


Figure 4. Similarities between two approaches of assessing local populations' vulnerability. Source: Authors' construction.

5.1. Households' Sensitivity to Human–Wildlife Conflicts

According to the IPCC approach of vulnerability (Table 5), the sensitivity analysis takes into account the components Water and Food, the components with the highest vulnerability index in the LVI model. This means that populations around the Pendjari Biosphere Reserve are highly sensitive to HWC, as farming and livestock breeding are their main sources of food and income. The HWC has led to an average loss of 25% of the cultivated area around the Pendjari Biosphere Reserve. This results in an annual loss ranging from 94.64 USD to 311.8 USD, depending on the type of crop [12]. This value is comparable to the cost of the damage caused by hippos around the Mono Delta Transboundary Biosphere Reserve, estimated at 254.54 USD by [29]. Although this cost might seem insignificant, it is a heavy burden for the local communities, who live on less than a dollar a day. Crop raiding around the Pendjari Biosphere Reserve not only causes a loss in the quantity of food, but also reduces the quality of the food supply by decreasing the diversity of food items. Additionally, livestock predation reduces the farmers' access to animal protein. As demonstrated in Uganda by [30], HWC have a negative impact on farmers' nutrition and health in the long run. Poor health will impede their production for the following year to feed their family or to protect their fields or livestock against raiders and predators. When animals destroy a field, farmers not only lose their food, but they also lose their ability to sow new fields. Usually, farmers collect seeds from their older fields to sow new ones. However, if the older fields have been destroyed and they do not have relatives willing to share their seeds, they need to purchase new seeds from the market. If the farmers have lost their crops to human–wildlife conflicts, they lose their source of income and face difficulties in buying new seeds. Because of the snowball effect of early harvesting and a decreased ability to plant new fields, farmers lose food and income during the raid and predation period as well as in the following months and years [7].

The main crops destroyed around the Pendjari Biosphere Reserve are cereals and cotton. This suggests that the intrusion of wildlife into crops jeopardizes both the food [16] and financial stability of households, as cotton serves as the primary source of income for

Beninese farmers, and Benin holds the top position for cotton production in Africa [31]. Food security refers to the state in which individuals have access to an adequate amount of food that is of good quality, safe to consume, and culturally acceptable, ensuring a healthy and fulfilling life at all times. Economic security, on the other hand, involves the ability to access basic necessities such as healthcare and education through a stable income [7,32]. Both food and economic insecurity contribute to absolute poverty, which depends not only on income but also on access to services. If HWC has a negative effect on both food and economic safety, then it can increase vulnerability to poverty. Additionally, poverty is often strongly linked with an increased vulnerability to disasters, as shown by [33]. Additionally, refs. [5,6] demonstrated that in Uganda, poorer households are more vulnerable to HWC because they can only afford land on the forest edge, which is the area most susceptible to raiding [7]. The Pendjari Biosphere Reserve, situated in the Atacora department in northern Benin, is plagued by high levels of poverty [34] and food insecurity among households [35]. This area in Benin experiences trends of food and economic insecurity among households, which could be exacerbated by the destruction of local staple crops (maize, sorghum, rice, and millet), cash crops (cotton), and livelihood assets (such as cattle and goats) [36], by the prevalence of interactions with wild animals from the Pendjari Biosphere Reserve, where HWC are reported to be on the rise [14].

5.2. Households' Adaptive Capacity to Manage Human–Wildlife Conflicts

To cope with the impact of wildlife's damage on their livelihoods, local communities develop livelihood strategies or rely on their social network. The greater vulnerability index of these components reveals the low adaptive capacity of households to manage the HWC around the Pendjari Biosphere Reserve.

Livelihood strategies consist of the implementation of mitigation measures. However, both raiders and predators are protected species, and due to this status, farmers are limited in their response to HWC. They need to use non-lethal deterrent methods not only because they have a positive perception of wildlife and conservation [37], but also because the law does not allow them to use lethal methods. The most frequently used non-lethal method is the guarding of the fields or livestock against damage, but the success of this method is limited for nocturnal raiders and predators like elephants, warthogs, and hyena [12,38]. Farmers who want to protect their crops from animals that cause damage often build huts in the fields and spend the night there. However, this puts them at a high risk of contracting malaria, which is a mosquito-borne disease that is endemic in Africa [39,40]. Moreover, guarding the fields both during the day and at night requires increased physical effort, loss of sleep, and increased stress, which can reduce the ability to devote time to education and other economic opportunities [39–42]. This, in turn, creates a vicious cycle, because low levels of education increase vulnerability to poverty and low resilience to HWC [43]. On the other hand, improving access to formal education could considerably reduce households' ability to guard the fields, and thus increase their vulnerability to HWC. This is because children who attend school will not be able to help in the fields, and yet they are mainly in charge of the field guarding activities in the household [43,44]. HWC is, therefore, a problem with diverse implications and causes, and its vulnerability is the result of a complex and subtle balance between demographic, socio-economic, and political factors [7].

Agricultural diversification and the search for non-agricultural and paid activities are other livelihood strategies of the local populations around the Pendjari Biosphere Reserve, but the low contribution of those strategies to deal with the impacts of HWC can be explained by the sociodemographic characteristics of the farmers and the recent changes in the governance of the reserve. There is a low index of agricultural diversification due to African Parks' restrictions on activities such as fishing, small-scale hunting, timber collection, charcoal making, and other non-timber forest products [45]. There is also a low percentage of households with access to non-agricultural activities due to their low

level of education, which does not allow them to take advantage of alternative economic opportunities [46].

Social Networks are a major component of the LVI and a sub-component of the component “Adaptive Capacity” (Table 5). Our results also revealed that Social Networks are the most vulnerable component, revealing that local populations have very low adaptive capacity to manage HWC around the Pendjari Biosphere Reserve. Similar results were found by [3,17,24], who concluded that Social Networks are the most vulnerable component of households to natural hazards. This can be explained by the fact that Social Networks are linked with almost all of the other components. Indeed, as agricultural households, vulnerability to the Natural Capital component will affect Food and Water components, and later, Social Networks. Also, vulnerability to Socio-Demographic Profiles will affect Livelihood Strategies and Social Networks.

The study’s findings align with previous research on household vulnerability to natural hazards. These earlier studies have demonstrated that households are more vulnerable to natural hazards in terms of food, social networks, water, and livelihood strategies; see, for example, refs. [3,47,48].

6. Conclusions

As around many protected areas in developing countries, agricultural households living around the Pendjari Biosphere Reserve in Northern Benin experience HWC that threaten their livelihoods. They are particularly vulnerable to Food, Water, and Livelihood strategy components. This is due to the importance of agriculture, livestock breeding for subsistence purposes, and recent restrictions to hunting, fishing, and the small-scale harvesting of non-timber forest products imposed by African Parks. Rather than completely prohibiting access to resources, access can be controlled as it was under CENAGREF governance. This could partially offset crop losses and reduce the economic and food impact of wildlife damage. It is important to strengthen measures to reduce the food and economic insecurity and social vulnerability of local populations. Developing income-generating activities can contribute to improving human–wildlife coexistence and security around the Pendjari Biosphere Reserve.

A new threat has been added to local populations’ vulnerability around the Pendjari Biosphere Reserve in Northern Benin; this is jihadist attacks, which have been frequent in the North of Benin since 2019. Future research is expected to assess the vulnerability of local populations, taking this new and recent threat into account.

Author Contributions: Conceptualization, S.E., E.A.S., Y.Z.M. and B.H.; methodology, S.E., E.A.S., Y.Z.M. and B.H.; software, S.E.; validation, E.A.S., Y.Z.M. and B.H.; formal analysis, S.E.; investigation, S.E.; resources, S.E.; data curation, S.E.; writing—original draft preparation, S.E.; writing—review and editing, S.E., E.A.S., Y.Z.M. and B.H.; visualization, S.E.; supervision, R.C.T., B.H. and B.A.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by ARES-CCD postdoctoral scholarship of UCLouvain Saint-Louis, Brussels, Belgium for the academic year 2022–2023.

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

Acknowledgments: We are very grateful to comments provided by the three anonymous reviewers as well as an Assistant Editor. We of course remain solely responsible for any remaining mistakes.

Conflicts of Interest: The authors declare no conflict of interest.

Notes

- ¹ Note that wildlife impacts on aquatic activities are not listed under Natural Hazards (HWC) in Table 2. This is due to the fact that aquatic activities used to take place at the Pendjari River inside the Reserve; but when African Park arrived in 2017, access to resources, including fishing activities, became prohibited. As a result, during our data collection in 2019, we were unable to gather data on the impact of this change on aquatic activities.

- ² Note that the ban on accessing resources made it impossible to gather data on the “Percentage of households with access to forest products”, resulting in an empty entry in the “Natural Capital” in Table 4.

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