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Vulnerability to Climate Variability and Anthropogenic Actions in Burkina Faso: A Case Study of the Neighboring Communities of Dinderesso and Peni Classified Forest

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Protected areas' vulnerability assessments of neighboring communities fail to fully account for the relationship among climate, protected areas, and human activities, making it challenging to manage biodiversity sustainably and preserve neighboring communities' livelihoods. This study aims to evaluate the vulnerability of eight neighboring communities of Dinderesso and Peni classified forest to climate and human activities through a simplified and consistent framework. Eight focus groups were conducted using a semi-structured questionnaire addressed to resource persons from eight neighboring communities. They assessed their vulnerability using a participatory research method. The categorial qualitative data collected were normalised and analysed using an arithmetic method in the Excel spreadsheet before being mapped using the software QGIS 3.18. The analysis revealed that neighboring Dinderesso and Peni classified forest vulnerability to climate and human activities ranges from low to moderate due to climate, socio-economic conditions, geographical location, topography, altitude, and management policies of the protected areas. These findings emphasise the importance of considering the vulnerability of neighboring communities to climate and human activities in the management plans and investments for protected areas by policymakers, forest managers and stakeholders. This is essential for advancing biodiversity conservation and safeguarding the well-being of local communities.

Keywords: Vulnerability; neighboring communities; classified forest; Dinderesso and Peni; Burkina Faso.

1. INTRODUCTION

The impacts of forest deforestation and degradation are numerous and severe, spanning various to domains. These are caused by the influence of biodiversity losses and climate change and may lead to desertification of certain areas, each posing a significant threat to our livelihoods sustainability [1]. The index specialised in forest biodiversity assessment revealed a loss of 1.7 percent per year of biodiversity worldwide due to deforestation and forest degradation [2]. Deforestation and forest degradation contribute to climate change in many countries worldwide, which face climate change induced warming and extreme events such as droughts and flooding [3]. This climate change warming is also recognised as a result of biophysical process effects with forest structure changes [4].

As a contribution to sustainable forest management, many studies have shown that human activities are the main drivers of deforestation and forest degradation [2], Lawrenceet al [5-7]. Working on the local perception of vegetation dynamic drivers, Fayeet al [8] highlighted that charcoal production, bushfires, and cattle overgrazing were the main drivers of the Missirah deforestation and forest degradation in Senegal. According to Savadogo et al [9], bad practices in medicinal tree species exploitation are responsible for the absence of adult trees. All these impacts were related to deforestation and forest degradation affecting human livelihoods [2], [10], [11]. According to Asamoah et al [12], forest degradation will affect communities that depend on the forest for food, fodder for livestock, house construction, and fencing. In Burkina Faso, the forest situation is characterised by deforestation and forest degradation.

In only 22 years, from 1992 to 2014, the forest area lost in the country was assessed to be almost half of all the country's forest areas [13]. The country lost 247 145 ha of forest area annually [14]. Analysing the dynamics of protected areas, many authors have highlighted the problems associated with deforestation and forest degradation [6], Dimobe et al [15-17]. The research on the Toessin forest dynamics revealed that human activities such as traditional agricultural practices and illegal wood exploitation are the key drivers of deforestation and forest degradation [18]. According to Tindano et al [19] research findings, gold mining contributed to plant species scarcity in the Kari classified forest in western Burkina Faso due to tree cutting and soil excavation. The loss of forest areas led to several previous studies [20-22] that provided detailed and meaningful information on forest resources' depletion.

Deforestation and forest degradation were caused essentially by the relationship between forests and human activities [14], [17], paradoxically affecting neighboring communities with a strong relationship with forests. Many authors agree that deforestation and forest degradation negatively affect populations' livelihoods [23] [18] [2]. Looking at medicinal plants' contribution to communities living close to the forest, [12] declared that deforestation and forest degradation would induce health issues in the population.

In Burkina Faso, the vulnerability studies related to forests have focused on forest species [24,25,21]. Some studies addressed neighboring communities' adaptation capacities and resilience to deforestation and forest degradation [21], [26]. However, there is a need to fill the knowledge gap on neighboring forest communities’ vulnerability to climate and human activities on forest degradation and deforestation at a local level, making it difficult to address all disaster risk management measures for improved and sustainable relationships between forests, humans, and climate influences efficiently. The current study seeks to improve knowledge of the relationships between climate, forest, and humans for better disaster risk management. More specifically, this study aims to assess Dinderesso and Peni's classified forest neighboring communities' (i) vulnerability and (ii) identify factors explaining this vulnerability of neighbroing communities.

2. MATERIALS AND METHODS

2.1 Study Area

The study was carried out in 08 rural neighboring communities of the Dinderesso classified forest (Nasso, Dinderesso, Banakeledaga, and Ouolonkoto) and Peni classified forest (Peni, Taga, Sokouranie, and Gnafongo) located in the Hauts-Bassins region, more precisely in the Houet province (Fig. 1). The study area is in the Sudanian climatic zone, where the rainy season lasts from Mai to October, with mean annual rainfall varying between 900 mm and 1100 mm. The temperature of the province ranges from 20 to 25℃. The vegetation is mainly represented by savannahs and gallery forests with dominant tree species such as *Vitellaria paradoxa*, *Parkia biglobosa*, *Lannea macrocarpa*, *Tamarindus indica*, and herbaceous species belonging to Cymbopogon, Pennisetum genera [5].

The surface terrain of the study area consists of plains, plateau, rough terrain, and undulating hills. The altitude average of the study area is 430 m, which is greater than the country's average altitude of 350 m. [27]. Many types of soils exist in the study areas, among which the representatives are sesquioxide soils, rich in iron or manganese oxide resulting from the decomposition of tropical ferruginous soils with little or no leaching and hydromorphic soils [28].

2.2 Vulnerability Assessment

The current study on community vulnerability assessment has been achieved through a conceptual framework adapted from the vulnerability assessment framework developed by GIZ [29]. The vulnerability is assessed in this conceptual framework using exposure, sensitivity, and adaptation capacity components (Fig. 2). The exposition component refers to the exposure of forest provisioning ecosystem services to climate variability factors such as drought, rainfall, and temperature. The sensitivity in this study is mainly observed in the interactions between communities and forest provisioning ecosystem services, as well as natural environmental effects. The potential impact involves both direct and indirect effects on forest provisioning ecosystem services due to degradation and losses. The adaptation capacity includes all the resources available within communities to overcome or mitigate potential impacts.

2.3 Simplified Vulnerability Assessment Chain Impacts

The impact chain in vulnerability assessment is important in identifying vulnerability variables. Based on the literature review, there are pieces of evidence that forest degradation and deforestation are mainly linked to human activities [5], MEEEA [14-16] and that forest provisioning ecosystem services plays an important role in the interactions between human and forests [17], tecnique national REDD [30-32]. Based on these considerations, the chain impact has been designed to identify the direct and indirect impacts of climate variability and human activities on forest provisioning ecosystem services and the community. Fig. 3 shows the simplified impact chain used to assess communities' vulnerability.

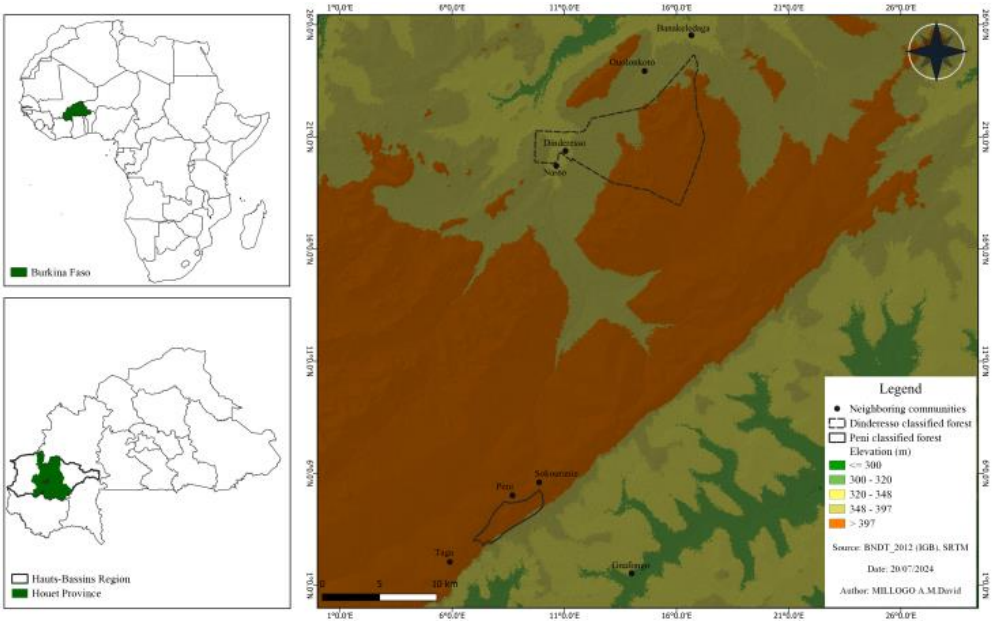

Fig. 1. Map of the study area
(Source: Millogo, 2024)

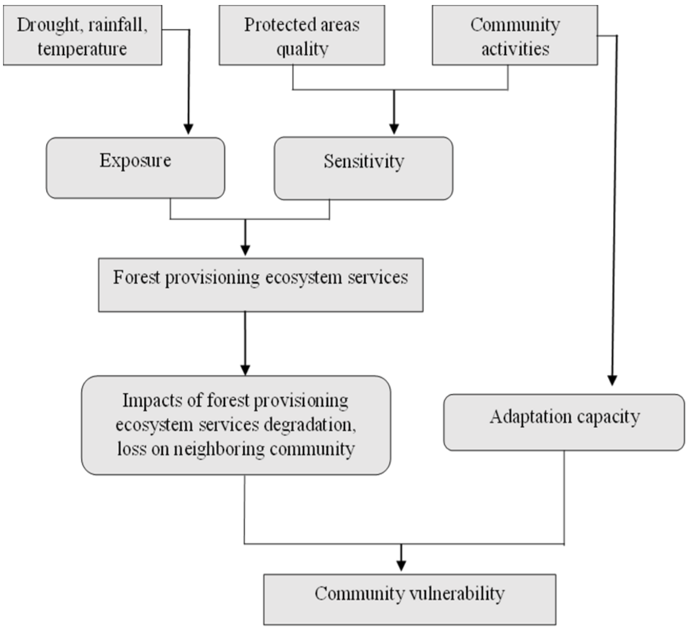

Fig. 2. Vulnerability assessment framework of protected areas neighboring communities
(Source: adapted from GIZ, 2017)

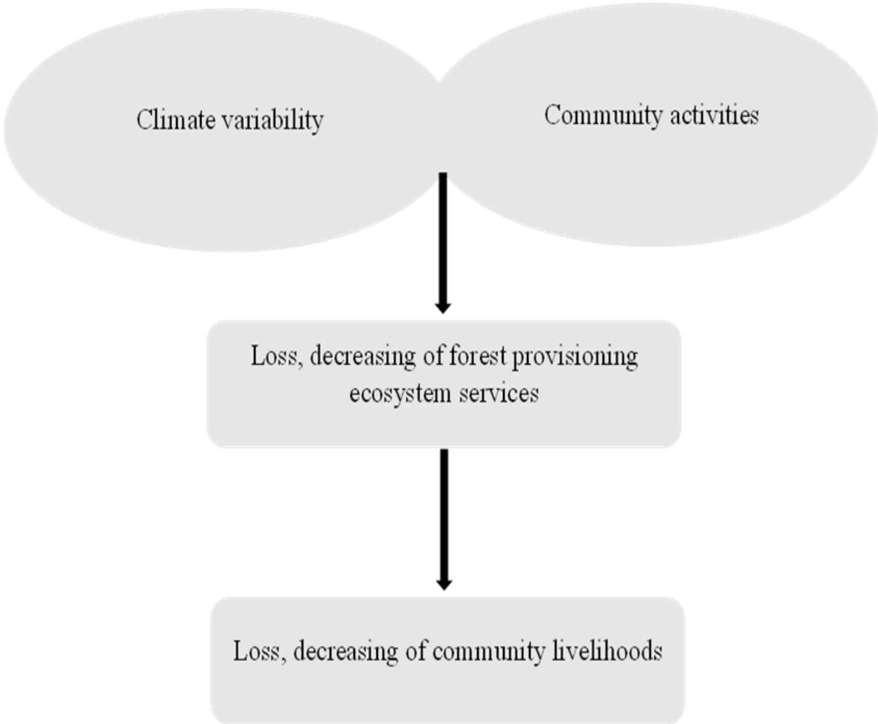

Fig. 3. Simplified impacts chain of protected areas neighboring social vulnerability assessment
(Source: Adapted from GIZ, 2017)

2.4 Components and Variables of Communities' Vulnerability Assessment

Considering the vulnerability impact chain, the literature review, and exchanges with resource persons working in Dinderesso and Peni classified forest management, 36 qualitative categorical variables have been identified to assess exposure, sensitivity, and adaptation capacity components. Table 1 shows details of the components and variables used for communities' vulnerability assessment.

2.5 Resource Person Identification

The choice of participants is a key point in vulnerability assessment vulnerability assessment. To achieve a consistent choice of these participants, ten consulting meetings have been held with each studied community public, customary administration authorities, and authorities in charge of Dinderesso and Peni classified forest management. These meetings allowed the identification of resource persons from each community as participants in the vulnerability assessment. These resource persons involve various socio-professional groups in each community, such as traditional medicine practitioners, farmers, livestock keepers, fishermen, artisans, local public and customary authorities, as well as the Ministries of Forest, Agriculture, and Livestock in Houet province.

The number of resource persons ranges from 13 to 20 for Nasso and Ouolonkoto, respectively. Resource persons were mainly male, with a percentage ranging from 76.92% to 94.12% for Nasso and Dinderesso, respectively. The percentage of females ranges from 5.88% to 23.08% for Dinderesso and Nasso, respectively. The minimum percentage of resource persons aged between 18 and 35 is 7.69% for Peni, and the maximum is 38.46% for Nasso. The minimum percentage of resource persons aged 36 years and older is 61.54% for Nasso, and the maximum is 92.31% for Peni. Table 2 shows the details of the resource persons.

2.6 Variables Validation and Assessment

Each neighboring community resource person participated in an individual focus group to validate and assess vulnerability variables. Eight focus group sessions (Photo 1, 2) were then conducted for the eight neighboring communities studied. Each validation and assessment session lasted 4 to 5 hours. The Active Participatory Research Method (APRM) was applied during the vulnerability variables validation and assessment process. The APRM is a flexible and interactive method that enables each community resource person to validate and assess vulnerability variables in their village through discussion among them, with a unique consensus answer provided. Following the validation of the variable, each community resource person assessed the vulnerability component variables using a scale ranging from 1 to 5, with 1 corresponding to the favorable situation (very low risk of vulnerability) and 5, a situation to improve (Very high risk of vulnerability). A semi-structured questionnaire related to exposure, sensitivity, and adaptation capacity was used to assess each vulnerability component variable.

2.7 Variables Normalisation

All the categorical variables assessed by each village participant have been normalised to convert them into a new score scale from 0 to 1. Using the corresponding Table 3, the categorical variables' scores have been transformed into metric values ranging from 0 to 1 to achieve this normalisation.

2.8 Components Variables Indicators Weighting

Given the high number of variables (36) for neighboring communities' vulnerability assessment, the current assessment applies equal weighting to all variable indicators. All the variables are considered to have the same weight.

2.9 Components Indicators and Vulnerability Assessment

The vulnerability component indicators have been calculated by the arithmetic method [29]. The arithmetic method is simple, easy to understand, and reduces bias when merging vulnerability component variables for calculating composite indicators. The following equations were used to calculate the vulnerability of neighboring communities in an Excel spreadsheet:

$$(1): EI = \frac{(I_1 + I_2 + I_3 + \cdots I_n)}{n}$$

$$(2): SI = \frac{(I_1 + I_2 + I_3 + \cdots I_n)}{n}$$

$$(3): PII = \frac{(EI + SI)}{2}$$

$$(4): ACI = \frac{(I_1 + I_2 + I_3 + \cdots I_n)}{n}$$

$$(5): CVI = \frac{(PII + ACI)}{2}$$

Note: EI= corresponding to Exposure indicator component, SI = Sensitivity indicator component, PII= Potential impact indicator, ACI = Adaptation capacity indicator component, n = number of component variable indicator, and CVI = Community vulnerability indicator; I1, I2, I3, In the component individual variable indicator.

After evaluating vulnerability indicators on a scale of 1 to 5, we assigned class values and colours to represent exposure, sensitivity,

Table 1. Components variables' contribution to vulnerability

Component	Factor	Variable	Variable contribution to vulnerability
Exposure	Drought	The frequency of drought events in the village last ten years	The high frequency of drought events increases vulnerability
		Drought duration events last ten years	High drought duration events increase vulnerability
		Drought severity events last ten years	High drought severity events increase vulnerability
		Drought spatial coverage	High drought spatial coverage increases vulnerability
	Rainfall	Rainfall evolution last ten years	Decreasing rainfall evolution increases the vulnerability
		Rainfall spatial coverage last ten years	Less rainfall spatial coverage increases vulnerability
	Temperature	Temperature evolution last ten years	Increasing temperature evolution increases vulnerability
Sensitivity	Protected area quality	Forest degradation level	High forest degradation levels increase vulnerability
	Community activities	Population density level	High population density increases vulnerability
		Level of forest exploitation for population food needs	High forest exploitation for population food needs increases vulnerability
		Level of forest exploitation for firewood	High forest exploitation for firewood increases vulnerability
		Level of forest exploitation for medicinal needs	High forest exploitation for medicinal needs increases the vulnerability
		Level of forest exploitation for incomes	High forest exploitation for income increases the vulnerability
		Level of forest exploitation for breeding	High forest exploitation for breeding increases the vulnerability
		The growth rate of agricultural land	The high growth rate of agricultural land increases vulnerability

Component	Factor	Variable	Variable contribution to vulnerability
		Frequency of bushfires over the last ten years	The high frequency of bushfires increases the vulnerability
		Bushfires spatial coverage	High bushfire spatial coverage increases vulnerability
		The practical intensity of real estate activity	The high practical intensity of real estate activity increases vulnerability
		Intensity of gold mining	High intensity of panning for gold increases vulnerability
		Spatial coverage of gold panning	High spatial coverage of gold panning increases vulnerability
Adaptation capacity	Knowledge	Level of population education/literacy	Low levels of population education/literacy increase vulnerability
		Level of population awareness of forest degradation	A low level of population awareness of forest degradation increases the vulnerability
		Level of population awareness of climate change	A low level of population awareness of climate change increases vulnerability
		Level of population awareness of drought impact management	A low level of population awareness of drought impact management increases vulnerability
		Level of population awareness of forest management	A low level of population awareness of forest management increases vulnerability
		Level of population participation in forest management	Low levels of population participation in forest management increase the vulnerability
	Technology	Level of population access to weather forecasts	A low level of population access to weather forecasts increases the vulnerability
		Level of population access to energy sources other than firewood	Low-level access of the population to energy sources other than firewood increases vulnerability
	Institutions	Level of awareness of the existence of customary forest management regulations among the population	Low level of awareness of the existence of customary forest management regulations among the population increased vulnerability
		Level of awareness among the population of the existence of public forest management regulations	Low level of awareness among the population of the existence of public forest management regulations increase vulnerability
		Level of respect for customary forest management regulations by the local population	Low level of respect for customary forest management regulations by the local population increased vulnerability
		Level of respect for public forest management regulations by the local population	Low level of respect for public forest management regulations by the local population increased vulnerability
		Level of efficiency of private forest management organisations	The low-level efficiency of private forest management organisations increases vulnerability
		Level of efficiency of public forest management organisation	The low level of efficiency of public forest management organisations increases vulnerability
	Economy	Level of population access to health services	Low levels of population access to health services increase vulnerability
		Level of household income in the village	Low levels of household income in the village increase the vulnerability

(Source: Adapted from GIZ, 2017)

Table 2. Characteristics of resource person participants to communities' vulnerability assessment

Neighboring community	Classified forest	Resource persons	Sex (%)		Age range (%)	
			Male	Female	[18-35]	[36 and + [
Dinderesso	Dinderesso	17	94.12	5.88	23.53	76.47
Nasso		13	76.92	23.08	38.46	61.54
Ouolonkoto		20	90	10	10	90
Banakeledaga		16	93.75	6.25	12.5	87.5
Taga	Peni	15	93.33	6.67	13.33	86.67
Peni		13	92.31	7.69	7.69	92.31
Gnafongo		15	93.33	6.67	13.33	86.67
Sokouranie		14	92.86	7.14	28.57	71.43
Min		**13**	**76.92**	**5.88**	**7.69**	**61.54**
Max		**20**	**94.12**	**23.08**	**38.46**	**92.31**

(Source: Millogo, 2024)

Photo 1. Vulnerability session assessment with Ouolonkoto community (ZERBO G.C)

Photo 2. Vulnerability session assessment with the Gnafongo community (ZERBO G.C)

Table 3. Categorical variables normalisation table scores (GIZ, 2017)

Categorical variable class	Normalisation range score from 0 to 1	Normalised score from 0 to 1	Description
1	0-0.2	0.1	No situation improvement needs
2	> 0.2-0.4	0.3	Positive situation
3	> 0.4-0.6	0.5	Neutral situation
4	> 0.6-0.8	0.7	Negative situation to improve
5	> 0.8-1	0.9	Criticise situation to be improved

adaptation capacity, and community vulnerability levels using QGIS software version 3.18 for mapping outputs.

3. RESULTS

3.1 Communities Vulnerability Components Indicators

The vulnerability component indicators of both Dinderesso and Peni classified forest neighboring communities' exposure, sensitivity, adaptation capacity, and vulnerability (Table 4) indicated the existence of different variabilities. The exposure indicator values ranged from 0.4 for Banakeledaga, Nasso, Ouolonkoto, and Sokouranie neighboring communities to 0.7 for Taga and Peni neighboring communities. The sensitivity variables indicator values ranged from 0.5 for the Gnafongo and Sokouranie neighboring communities to 0.7 for the Nasso, Ouolonkoto, and Peni neighboring communities. The values of adaptation capacity indicators ranged from 0.3 for the Nasso community to 0.5 for the Ouolonkoto, Gnafongo, and Peni neighboring communities. Vulnerability indicator values ranged from 0.4 for the Banakeledaga, Nasso, and Sokouranie neighboring communities to 0.6 for the Peni community.

3.2 Neighboring Communities' Exposure to drought, Rainfall, andTemperature Variability

The analysis results of neighboring Dinderesso and Peni classified forest communities' exposure to drought, rainfall, and temperature evolution showed that communities are differently exposed to drought, rainfall, and temperature (Fig. 4). Neighboring Dinderesso classified forest communities' exposure varies from low exposure for Banakeledaga, Nasso, and Ouolonkoto communities to moderate exposure for the Dinderesso community. Concerning the neighboring communities of Peni classified forest, they experienced low exposure in Sokouranie and Taga, moderate exposure in Gnafongo, and high exposure in Peni.

3.3 Neighboring Communities' Sensitivity to Forest Provisioning Ecosystem Services Degradation, Losses

The results of neighboring Dinderesso and Peni classified forest communities' sensitivity to human activities in forest provisioning ecosystem services revealed a difference in sensitivity levels among communities (Fig. 5). The sensitivity levels among Dinderesso classified forest neighboring communities range from moderate for Banakeledaga and Dinderesso communities to high for Nasso and Ouolonkoto communities. The results of the sensitivity of neighboring Peni classified forest communities vary from moderate for Gnafongo, Sokouranie, and Taga to high for the Peni community.

3.4 Neighboring Communities' Adaptation Capacity to Provisioning Ecosystem Services Degradation, Loss

Fig. 6 revealed different levels among neighboring Dinderesso and Peni classified forest communities' adaptation capacities to face the impacts of forest provisioning ecosystem services degradation and loss. The results revealed that the Ouolonkoto community has a moderate adaptation capacity, while Banakeledaga, Dinderesso, and Nasso have a high adaptation capacity. The results showed that Peni classified forest communities such as Gnafongo and Peni have a moderate adaptation capacity; Sokouranie and Taga's communities have a high adaptation capacity.

3.5 Neighboring Communities' Vulnerability

The vulnerability results of neighboring Dinderesso and Peni classified forest communities to climate variability and human activities revealed different levels of vulnerability among communities (Fig. 7). Neighboring Dinderesso classified forest communities, including Dinderesso and

Ouolonkoto, experienced moderate vulnerability levels, while Banakeledaga and Nasso have low vulnerability levels. Concerning Peni classified forest neighboring communities, results highlighted that Gnafongo, Peni, and Taga have a moderate vulnerability level, and Sokouranie has a low vulnerability level.

Table 4. Exposure, Sensitivity, Adaptation capacity and vulnerability indicators (Millogo, 2024)

Community	Classified forest	EI	SI	ACI	CVI
Banakeledaga		0.4	0.6	0.4	0.4
Dinderesso		0.5	0.6	0.4	0.5
Nasso		0.4	0.7	0.3	0.4
Ouolonkoto	Dinderesso	0.4	0.7	0.5	0.5
Mean		**0.43**	**0.65**	**0.4**	**0.45**
Standard deviation		**0.05**	**0.06**	**0.08**	**0.06**
Ganfongo		0.6	0.5	0.5	0.5
Peni		0.7	0.7	0.5	0.6
Sokouranie		0.4	0.5	0.4	0.4
Taga	Peni	0.4	0.6	0.4	0.5
Mean		**0.53**	**0.58**	**0.45**	**0.5**
Standard deviation		**0.15**	**0.1**	**0.06**	**0.08**

Legend: EI= Exposure Indicator Component; SI= Sensitivity Indicator Component; ACI= Adaptation Capacity Indicator Component; CVI= Community Vulnerability Indicator

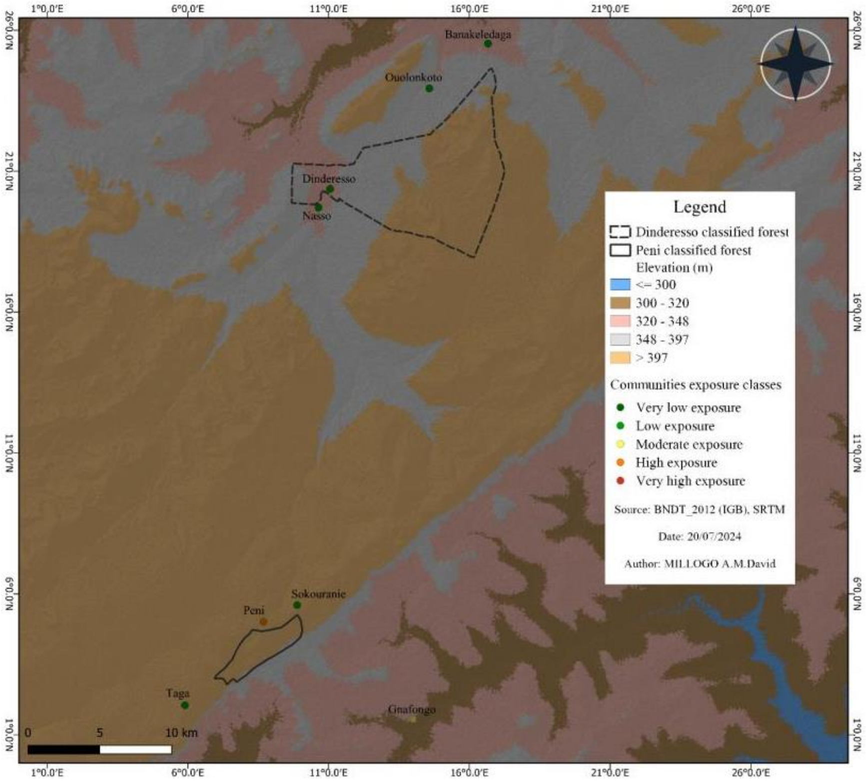

Fig. 4. Dinderesso and Peni classified forest neighboring communities' exposure to drought, rainfall, and temperature variability
(Millogo. 2024)

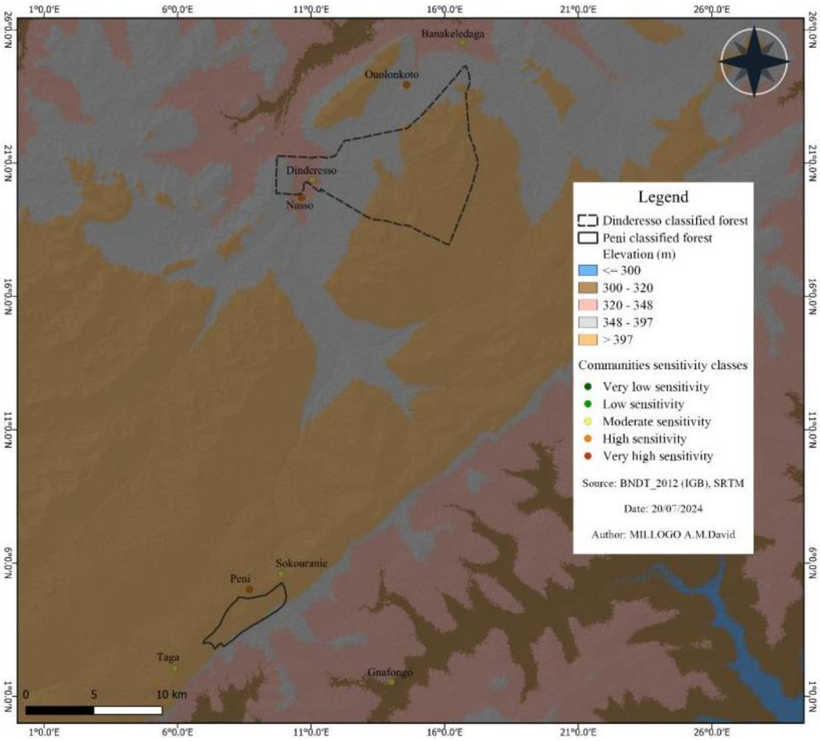

Fig. 5. Dinderesso and Peni classified forest neighboring communities' sensitivity to forest provisioning ecosystem services degradation and loss
(Source: Millogo, 2024)

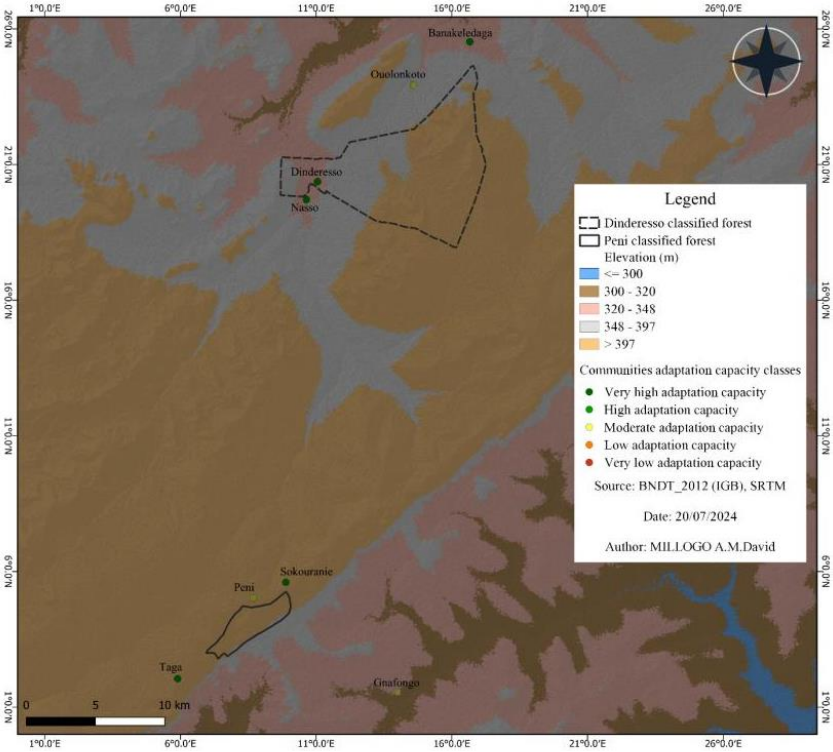

Fig. 6. Dinderesso and Peni classified forest neighboring communities' adaptation capacities to forest provisioning ecosystem services degradation and loss
(Source: Millogo, 2024).

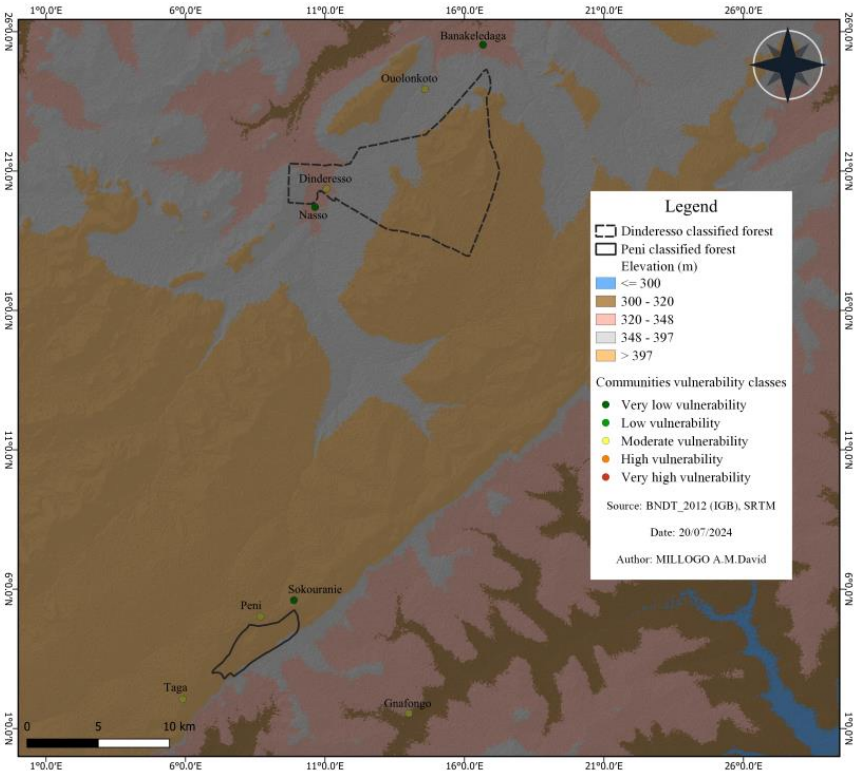

Fig. 7. Dinderesso and Peni classified forest neighboring communities' vulnerability to climate variability and human activities
(Source: Millogo, 2024)

4. DISCUSSION

4.1 Neighboring Communities' Exposure to drought, Rainfall, and Temperature Variability

The study revealed that neighboring communities of the two forests had been affected by climate variability, including changes in drought, rainfall, and temperature over the past decade. All neighboring communities reported experiencing at least one instance of drought during this period. They also perceived changes in rainfall decreasing and temperature increasing during the last ten years. These results align with the research of Runde et al [33], which predicted drought and warming increases within tropic areas from 30 North to 30 South. A spatiotemporal evolution analysis of rainfall in Burkina Faso from 1961 to 2010 highlighted decreasing rainfall from North to South [34]. Some research conducted in Bobo-Dioulasso, the province that hosted the current study area, predicted an increase in the temperature from 2012 to 2100 [35]. All the neighboring communities involved in this study are located in the same Sudanian climatic zone, so we could expect the same exposure level experienced by the communities.

However, the results showed that the exposure to drought, rainfall, and temperature is slightly different among the same neighboring classified forest communities and between each classified forest neighboring community group. This suggests that community exposure to climate change variability might not be only dependent on the geographical location but also on other criteria, encompassing topographical, community experiences with climate change and variability, events, their well-being statute, traditional knowledge, soil type, vegetation, and occupation which could influence perception to exposure [36-39]. Indeed, all the neighboring communities studied are not homogenous and present many variabilities at the topographical level, a diversity of ethnic groups composing each community with different habits and occupations.

During the participatory assessment of neighboring Dinderesso and Peni, classified forest communities' vulnerability, some community participants like Banakeledaga appreciated the exposure to drought based on drought impacts such as crop loss, yield decreases, forest tree mortality, and water point drying. So, because this given community is located in the lowlands with an altitude average of 300 m [40], they may not perceive some drought events with low impact on their livelihoods due to the lowlands' capacity to keep more water in the soil for a long time compared to some highlands such as the Peni community with an altitude average greater than 400 m. According to Köpp [41], areas with low altitudes may be less influenced by drought than areas with high altitudes due to the scarcity of water and nutrients for plants. This type of neighboring community may not appreciate the exposure to drought, rainfall, and temperature like other communities on the highlands.

Listening to other community participants, such as Peni, in addition to the severity of drought events, rainfall, and temperature evolution they experienced, their explanation of climate change and variability with precision showed the presence of consistent knowledge within the community of climate change, variability. This strong knowledge was noticed in the Peni community in addition to their location in the highland, and experience with drought events, rainfall, and temperature trends could explain their exposure to a high level. Outside of the Peni community, all the other communities' exposure to drought, rainfall, and temperature varies from low to moderate, which remains non- critical compared to high and very high exposure.

4.2 Neighboring Communities' Sensitivity

The results obtained from the participatory assessment of neighboring communities of Dinderesso and Peni classified forests' sensitivity related to forest provisioning ecosystem services, revealed a sensitivity variation from moderate to high, showing that all the neighboring communities share relations with named forests for provisioning ecosystem services in order to satisfy households' food needs, to treat diseases, to feed livestock, for buildings construction. Forests have contributed for a long time to rural communities' food security in support of crops [2], [42], [43]. According to Eshetu [44], firewood and charcoal production provide income to rural households and support their energy needs. Forest provisioning ecosystem services contribution to the rural communities' livelihoods with food, traditional medicine, fodder, and construction materials were mentioned by Savadogo [17], [45].

All the different neighboring communities' participants agreed that the relationship encompasses the benefits they got from the forest provisioning ecosystem services and other activities such as traditional gold mining, farm area growing, land and property activities, firewood, and community population density, for instance, are factors which may negatively affect directly or indirectly forest provisioning ecosystem services and also neighboring communities themselves. Some research highlighted that the population that shares more relations with natural resources may be more affected and more vulnerable if these natural resources products are disrupted or degraded [46]. Overexploitation of forest provisioning ecosystem services contributes to its degradation [47]. By practicing extensive agriculture, humans negatively contribute to forest provisioning ecosystem services degradation and loss [2], [5], [14].

Investigating forest degradation and deforestation in Ghana, [48] mentioned population growth, land tenure, and illegal mining as drivers. The results of the current study revealed that communities neighboring the two forests are differently affected by forest provisioning ecosystem services under human influence. The difference in sensitivity level observed among neighboring communities could be due to the intensity of the relationship each neighboring community shares with the forest, forest resource quality, community education status, community wealth status, and forest sustainable management system. Ouolonkoto community recognised that their relationship with the Dinderesso forest is important because most of their community women are, for instance, involved in charcoal production.

This activity provides them with income used to support their household needs. Some community participants, such as Dinderesso and Taga, consider that the forest is degraded, so they fail to find, as in the past, many forest products that they used to get in. So, this perception of forest degradation with the scarcity or the loss of many forest products, such as some fauna species and medicinal plants, reduces the intensity of their relation with their forest. Even if they are aware that their activities contribute to forest provisioning ecosystem services, neighboring communities of Dinderesso and Peni classified forests said that because of forest protection statute, they use to hide from forester managers to cut fresh trees for income and their household's energy needs, for making charcoal.

Some communities said that the training, advice, and support from public and private organizations allowed them to understand the relevance of preserving biodiversity and reshaped their relationship with forest provisioning ecosystem services.

Other communities claimed that they no longer have enough farmland for their children. To satisfy their needs, they cut some trees in the forest that are not fenced to make new farms and new houses for their children and replace their old farms that are no longer fertile. Other communities, such as Gnafongo, explained that they are far from the forest, reducing their relationship with providing forest ecosystem services. Some studies carried out at the household level showed that education level, the availability of trees as a resource, distance to the forest, and family size negatively or positively influence the dependence of households on fuel income [44].

Comparing the amount of forest provisioning ecosystem services sold by communities, [45] showed that some communities exploited and sold more forest provisioning ecosystem services than others. According to Mcdonald et al [49], the proximity of protected areas to urban cities contributes to forest area degradation. Interestingly, in environmental protection, Legutko-Kobus et al [50] highlighted the importance of an environmental protection framework to ensure good control and regulation of environmental areas.

4.3 Neighboring Communities' Adaptation Capacity

Regarding communities' adaptation capacities, the results revealed the presence of adaptation capacities within the neighboring communities of the two forests, with varying levels among all the communities. Adaptation capacities assessment under knowledge, technology, institutions, and economic factors allowed the identification of each community adaptation capacity level, which varies from moderate to high. Knowing climate change, variability, and human activities' impact on forest provisioning ecosystem services appears very important in disaster risk management. As a sub-factor of knowledge, education can help improve community knowledge and its adaptive capacity to prevent or cope with any disaster risk, such as forest provisioning ecosystem services degradation and loss. According to Wu and Lee [51], Choden et al [52], education improves adaptation capacity. During the participatory assessment of neighboring Dinderesso and Peni, classified forest communities said that training and news from media improve their knowledge of climate change, variability, and forest sustainability management.

By comparing participants' perceptions of education levels within their community, it appears that some communities have high and moderate education levels, which impact neighboring communities' adaptation capacity to forest provisioning ecosystem services due to drought, rainfall, temperature, and human activities. Higher education levels provide better information access and adaptation capacity [53], [54]. During the many years of projects, commitment to forest restoration with the support of environment offices enhanced neighboring communities' knowledge by training them on climate change, fauna species breeding, seedlings nursery production, tree planting, and so on. Looking at the increasing disaster risks in the world, particularly in West African countries, clear and precise information on time can improve adaptation capacities for better disaster risk management. For that, technology is very important to improve adaptation capacity. Many authors have already mentioned the key role of technology in communication in disaster risk management [55-57].

During the participatory exchange, neighboring communities of Dinderesso and Peni classified forest agreed that they sometimes received information about climate and forest sustainable management from public and private organisations. Concerning the device from which they got this information, they mentioned Phones, radio, and television. According to many socio-economic reasons, communities confirmed that within the community, some people may not have all these devices or do not have any one of the devices cited above, making it difficult for those people to get information on time to improve their adaptation capacity. This reality of access to technology among neighboring communities helps better understand the different adaptation capacity levels observed. Indeed, when some communities have high access to technology, which means a high likelihood of receiving climate and forest sustainable management information, other communities fail to receive the same information due to low access to technology.

To reduce the negative impacts of humans on forest provisioning ecosystem services, some community participants mentioned using alternative means of firewood such as crop residuals, biogas, and gas and improved cooking systems using less firewood. As an alternative to firewood, renewable energy reduces carbon dioxide emissions and improves community adaptation capacities at any location level [58]. Unfortunately, the cost of gas, biogas, and the limited stock of crop residuals are some reasons advanced by some community participants to explain their difficulty in using these alternative fuel energy sources. So, using this alternative energy source is not common within each community and differs among all the communities, explaining their different adaptation capacities. In disaster risk reduction, having institutions with policies, regulations, and measures put in place contributes to the control and reduction of human activities, which can cause negative impacts on forest provisioning ecosystem services and climate change variability.

In all the neighboring communities studied, participants confirmed the presence of environment offices from the public government, a local organisation for forest management created by the government environment office, and customary chieftaincy. All these institutions promote the reduction of carbon dioxide emissions following a set of public and local regulations. Despite all these efforts, community participants said that some people do not strongly respect these regulations. That situation negatively affects the adaptation capacities of communities with low respect for regulations compared to communities with high respect for regulations. In addition to respecting institutions' regulations by communities, participants assessed the efficiency level of both government and local institutions in forest sustainability management. Their responses showed different levels of efficiency for the government and local institutions within and among the communities.

According to participants, some institutions have moderate efficiency, which may not positively impact community adaptation capacities compared to communities where institutions have high efficiency. According to Chimanga and Kanja [56] and Anser [57], good institutions are necessary to improve adaptation capacities in disaster risk management. Concerning the economic contribution to adaptation capacity, neighboring communities revealed that most households have moderate and low income, which reduces their adaptation capacities [59,60]. Even if they recognised the efforts of green economy activities developed to improve and diversify their incomes, especially for Dinderesso's neighboring communities, which hosted many years of projects for forest sustainability management, communities still do not have the high income to improve their adaptation capacities.

Looking at the participants representing studied communities, there are several socio-professional groups, such as farmers, breeders, fishers, hunters, tradipraticians, retailers, and government workers; most of them depend on climate and forest products, negatively affecting communities' income and adaptation capacities. To improve communities' adaptation capacities, some solutions like income source diversification through green activities and financial credit from bank institutions have been recommended [61].

4.4 Neighboring Communities' Vulnerability

The vulnerability of neighboring Dinderesso and Peni classified forest communities under drought, rainfall, temperature variability, and human activities revealed different vulnerability levels ranging from low to moderate. These findings are consistent with many studies that have highlighted the differential vulnerability levels observed among communities [62-64]. Neighboring communities showing higher vulnerability are related to their adaptation capacity to cope with exposure and sensitivity. The Ouolonkoto community is more vulnerable because they share intense relationships that negatively affect forest livelihoods and ecosystem services, and it has lower adaptation to cope with the sensitivity issues. Peni community vulnerability is high because they face higher exposure and higher sensitivity with a lower adaptation capacity. Those communities experiencing low vulnerability levels have lower exposure, lower sensitivity, and higher adaptation capacity, such as Banakeledaga and Sokouranie communities.

In general, neighboring communities' vulnerability results are non-critical due to different projects' efforts that improved forest sustainability management, their neighboring communities' livelihoods, and many reasons related to the location, socio-economic characteristics, and classified forest management policy in place. In addition, all the stakeholders encompass public and private organisations and neighboring communities committed to Dinderesso and Peni classified forest sustainability management.

5. CONCLUSION

This study allowed the assessment of neighboring Dinderesso and Peni classified forest communities' vulnerability. The results showed the differential vulnerability among neighboring communities ranging from low vulnerability for Banakeledaga, Nasso, and Sokouranie neighboring communities to moderate vulnerability for Ouolonkoto, Dinderesso, Peni, Taga, and Gnafongo. This differential vulnerability observed among neighboring Dinderesso and Peni classified forests is due to many factors, including climate, geographical location, topography, altitude, socioeconomic characteristics, and forest resources management policies. The study findings emphasised the importance of considering the vulnerability of neighboring communities in classified forests management plans and investments by policymakers, forest managers and stakeholders. This is especially crucial for forest resource management plans and investments for sustainable biodiversity conservation and livelihood preservation. This approach can serve as a valuable tool in disaster risk management among climate, forest, and human relationships.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology Details of the AI usage are given below:

1. Grammarly has been used to enhance the manuscript's grammar structure.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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