Original Research Article

Vulnerability to climate variability and anthropogenic actions: the case of the neighboring communities of Dinderesso and Peni classified forest in Burkina Faso

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ABSTRACT

The contribution of neighboring communities to the sustainable management of protected areas has long been recognised, thanks to their relationships with these areas. However, the degradation of protected areas harms the lives of neighboring communities, whose livelihoods are inexorably diminishing. vulnerability fail to fully account for the relationship among climate, protected areas, and human activities. To remedy this, the present study proposes a simplified and consistent framework to assess the vulnerability of neighboring communities in protected areas' to climate variability and human activities. Using an active participatory research method, resource persons have qualitatively assessed eight neighboring communities of Dinderesso and Peni classified forests' exposure, sensitivity, adaptation capacity, and vulnerability. The vulnerability components indicators were computed using the arithmetic method in the EXCEL spreadsheet before mapping with the software QGIS 3.18. The vulnerability study results showed that neighboring communities are differently affected with regard to provisioning forest ecosystem services, deforestation and forerst degradation under climate and human activities have benn influence due to climate, socio-economic, geographical, topography, altitude characteristics variability, and classified forest policy management.

Keywords: Vulnerability; neighboring communities; classified forests, antrropogeniuc actions, ecosystem services

1. INTRODUCTION

The impacts of forest deforestation and degradation are numerous and severe, spanning to various domains. These are caused by the influence of biodiversity losses, climate change, and may lead to desertification of certain arreeas, each posing a significant threat to our livelihoods and sustainability [1]. The index specialized in forest biodiversity assessment revealed a loss of 1.7 percent per year of biodiversity worldwide due to deforestation and forest degradation [2]. Deforestatio 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 recognized 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], [5]–[7]. Working on the local perception of vegetation dynamic drivers, [8] highlighted that charcoal production, bushfires, and cattle overgrazing were the main drivers of the Missirah deforestation and forest degradation in Senegal. According to [9], bad practices in medicinal tree species exploitation are responsible for the absence of adult trees. All these impactswere related to deforestation and forest degradation affecting human livelihoods [2], [10], [11]. According to [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 characterized by degradation and deforestation. 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]. Analyzing the dynamics of protected areas, many authors have highlighted the problems associated with deforestation and forest degradation [6], [15]–[17]. The research work 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 [19] research findings, gold mining activities 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 initiate several studies [20]–[22] that provided detailed and meaningful information on forest resources' depletion. Deforestation and forest degradation and deforestation were caused essentially by the relationship between forests and human activities [14], [17], paradoxically affect the neighboring communities who have strong relationship with forests. Many authors agree that deforestation and forest degradation negatively affect populations' livelihoods [2], [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. Some efforts have been made to assess neighboring communities' adaptation capacities and resilience to deforestation and forest degradation [21], [23]. However, little attention has been paid as to how these communities are differently affected. Indeed, few scientific works on population vulnerability assessment related to their relationship to forests and climate have been achieved so far at a local level, making it difficult to address all disaster risk management measures for improved and sustainable relationship between forests, humans, and climate influences efficiently. The current study uses a simple and flexible assessment framework to investigate to the sustainable nexus of forests, neighboring communities, and climate change induced effects. More specifically, this study assesses Dinderesso and Peni's protected forests relationship with regard to (i) exposure, (ii) sensitivity, (iii) adaptation capacity, and (iv) factors affecting the vulnerability of neighboring communities.

2. material 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 (Figure 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 study the surface terrain of the study area consists of plains, plateau, rough terrain, and undulating hills. The altitude of the study area is 430 m a.s.l. which is greater than the country altitude average 350 m a.s.l [24]. 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 [25].

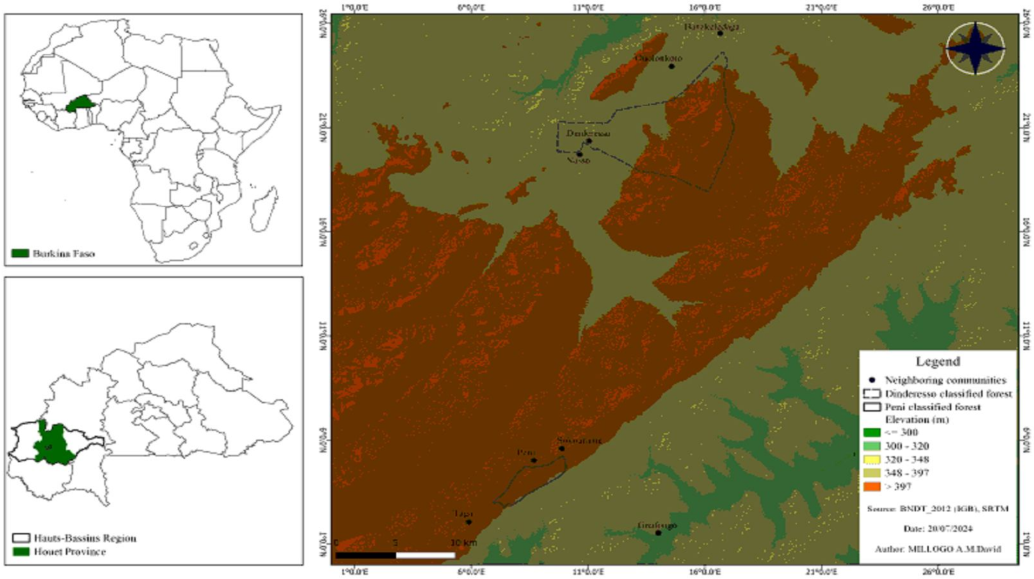


Figure 1 Map of the study area location (spources)

2.2 Vulnerability assessment

The current study on community vulnerability assessment has been achieved through a conceptual framework inspired by and updated by the vulnerability assessment framework developed by [26] and considering vulnerability assessment through exposure, sensitivity, and adaptation capacity components. The conceptual framework (Figure 2) considers exposition, sensitivity, potential impact, and adaptation capacity of the community for vulnerability assessment. The exposition component refers to forest provisioning ecosystem services exposure 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 is characterized by exposition and sensitivity components' direct and indirect impacts on forest provisioning ecosystem services. The adaptation capacity of the community encompasses all the means available within the communities to overcome or mitigate potential impacts.

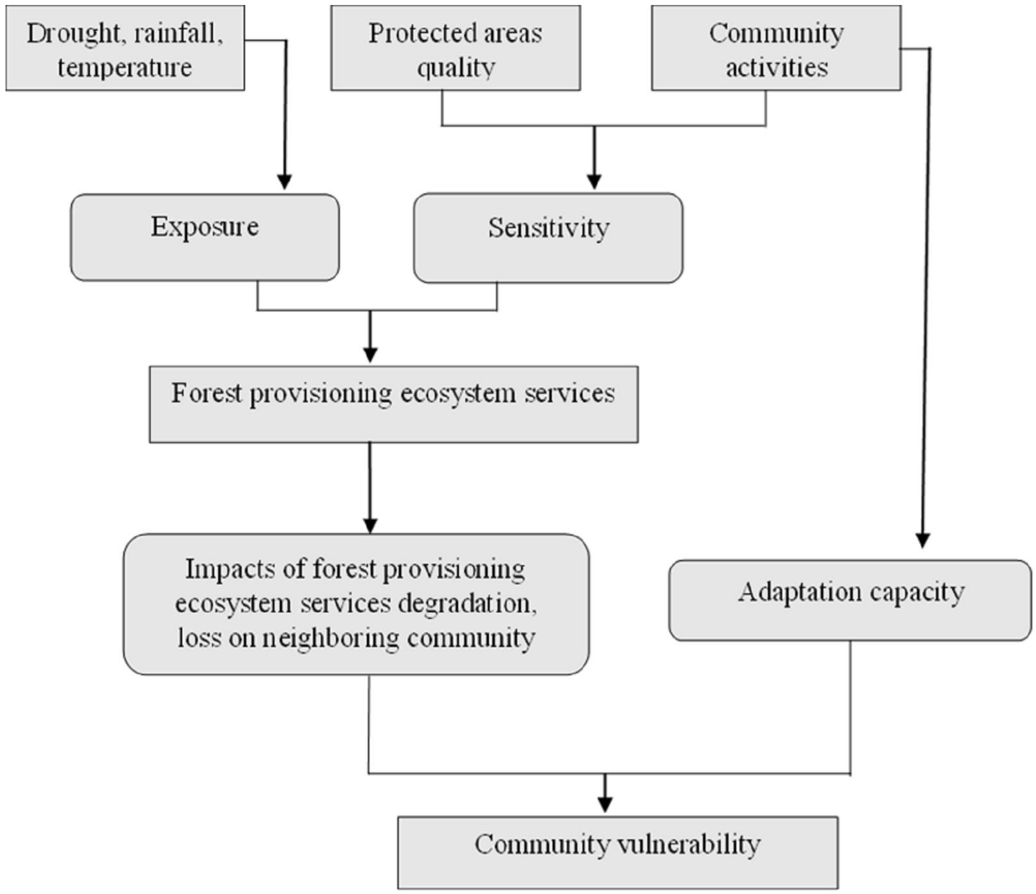


Figure 2: Vulnerability assessment framework of protected areas neighboring communities

2.3 Simplified vulnerability assessment chain impacts

The impact chain in vulnerability assessment is very important. Based on the literature review, there are pieces of evidence that forest degradation and deforestation are mainly linked to human activities [5], [14]–[16] and that forest provisioning ecosystem services play an important role in the interactions between human and forests [17], [27]–[29]. 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. Figure 3 shows the simplified impact chain used to assess communities' vulnerability (sourcea0.

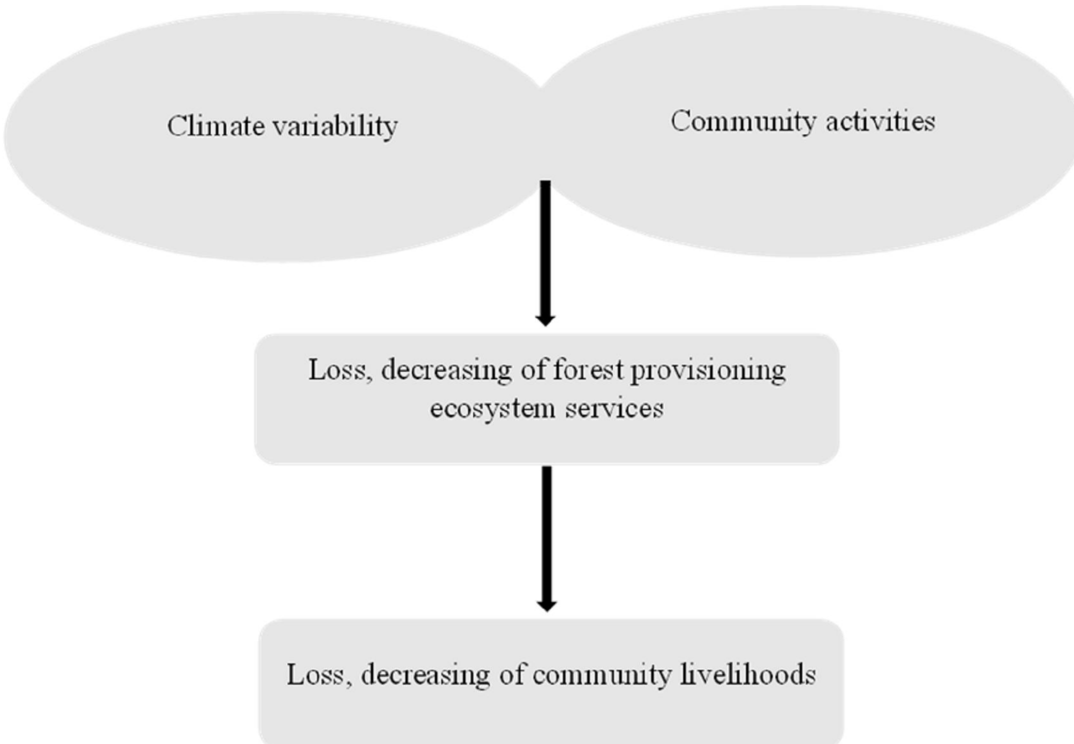


Figure 3: Simplified impacts chain of protected areas neighboring social vulnerability assessment (source)

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 in communities' vulnerability assessment.

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
		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 panning for gold	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 organizations	The low-level efficiency of private forest management organizations increases vulnerability
		Level of efficiency of public forest management organization	The low level of efficiency of public forest management organizations 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 of the table?

2.5 Resource person identification

Choosing participants to be involved in vulnerability assessment is a key aspect to consider. Regarding the following, meetings have been held to exchange with local authorities in charge of Dinderesso and Peni classified forests and those of the neighboring communities and stakeholders involved in Dinderesso and Peni classified forest management. These meetings aimed at identifying each neighboring community resource person with meaningful knowledge of their community and vulnerability variables to assess. In each neighboring community, resource persons have been chosen, considering local authorities of public and customary administration, as well as various socio-economic activities such as traditional medicine, agriculture, livestock, and artisan. Other resource persons from the Ministries in forest, agriculture, and breeding joined for vulnerability assessment. The number of leaders ranges from 13 to 20 participants, respectively, for Nasso and Ouolonkoto. Participants were mostly male, with a percentage ranging from 76.92% to 94.12%, respectively, for Nasso and Dinderesso. The percentage of females ranges from 5.88% to 23.08%, respectively, for Dinderesso and Nasso. The age of the participants ranged from 18 to 35 years for Peni, and the average age of the participants was 36 years for Nasso. The details of the vulnerability assessment of resource persons participants are shown in Table 2.

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?

2.6 Variables validation and assessment

Eight sessions (Photo 1, 2) of variable validation and assessment with one session per village have been achieved; each assessment session lasted 4 to 5 hours. All variable validation and assessment processes have been achieved using the Active Participatory Research Method (APRM). This flexible and interactive method allowed each community resource person to validate and assess vulnerability variables applied in their village through concertation among them and by consensus. After the validation of the variables list, each component variable was assessed by resource persons using a scale ranging from 1 to 5, with 1 corresponding to the favourable situation (very low risk of vulnerability) and 5, a situation to improve (Very high risk of vulnerability). A questionnaire related to exposure, sensitivity, and adaptation capacity was used during the vulnerability assessment with resource persons to assess each component variable fully.

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

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

2.7 Variables normalization

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 normalization.

Table 3: Categorical variables normalization 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

2.8 Components variables indicators weighting

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

2.9 Components indicators and vulnerability assessment

The assessment of each component indicator and community vulnerability has been achieved by applying the arithmetic method [26]. The arithmetic method is simple and understandable, and it reduces bias when merging variables within each vulnerability component to compute composite indicators. To compute neighboring community vulnerability through an Excel spreadsheet, the following equations have been used:

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 assessing components and neighboring communities' vulnerability indicators, using a scale of 1 to 5, the corresponding class value has been applied with the corresponding color to express the exposure, sensitivity, adaptation capacity, and community vulnerability level using QGIS software version 3.18 for mapping outputs.

3. results

3.1 Communities vulnerability components indicators

The variables indicators of both Dinderesso and Peni protected forest exposure, sensitivity, adaptation capacity, and vulnerability (Table 3), 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 range 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.

Table 4: Exposure, Sensitivity, Adaptation capacity and vulnerability indicators

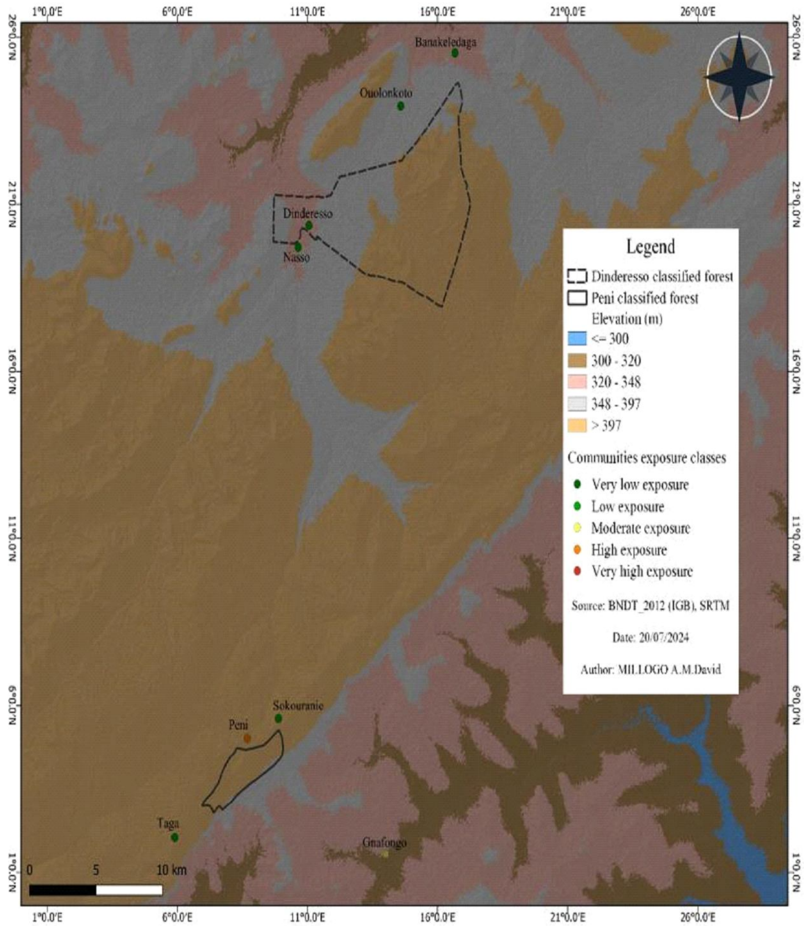
Community	Classified forest	EI	SI	ACI	CVI
Banakeledaga		0.4	0.6	0.4	0.4

Dinderesso		0.5	0.6	0.4	0.5
Nasso		0.4	0.7	0.3	0.4
Ouolonkoto		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	Peni	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		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 (source)

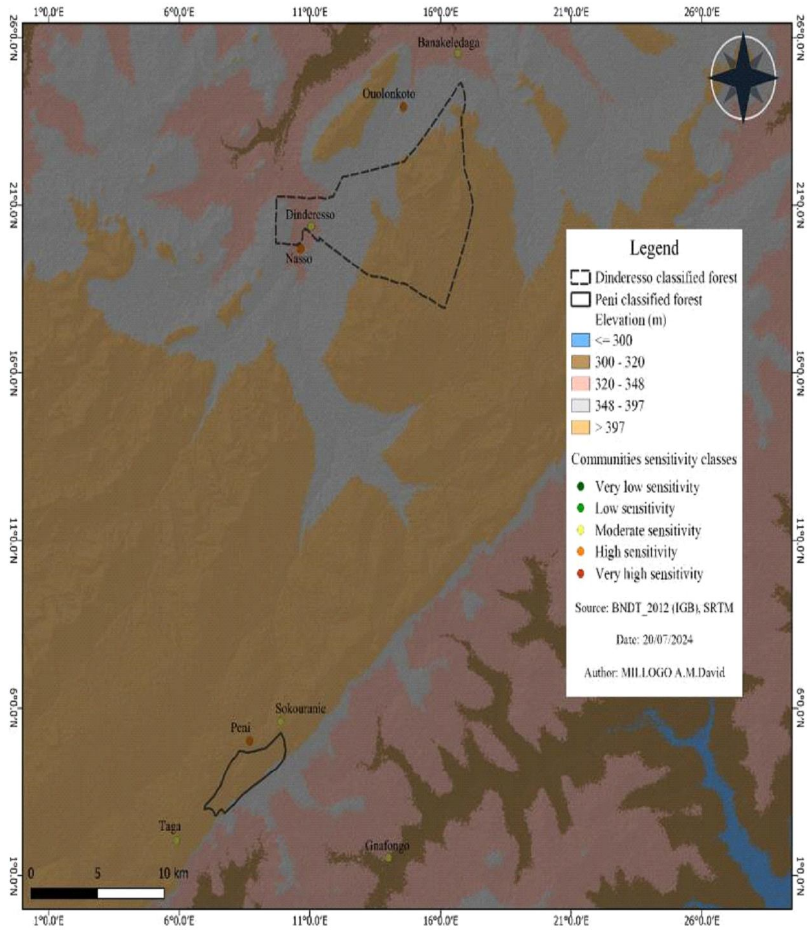
3.2 Neighboring communities' exposure to drought, rainfall, and temperature variability

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 effects (Figure 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 neighboring Peni classified forest communities, they experienced low exposure for the Sokouranie and Taga neighboring communities, moderate exposure for the Gnafongo neighboring community, and high exposure for the Peni neighboring community.



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 (Figure 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

Figure 6 revealed different levels among neighboring Dinderesso and Peni classified forest communities' adaptation capacities to face the impacts of forest provisioning ecosystem services. The results of the neighboring Dinderesso classified forest communities' adaptation capacity revealed that the Ouolonkoto community has a moderate adaptation capacity, and 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.

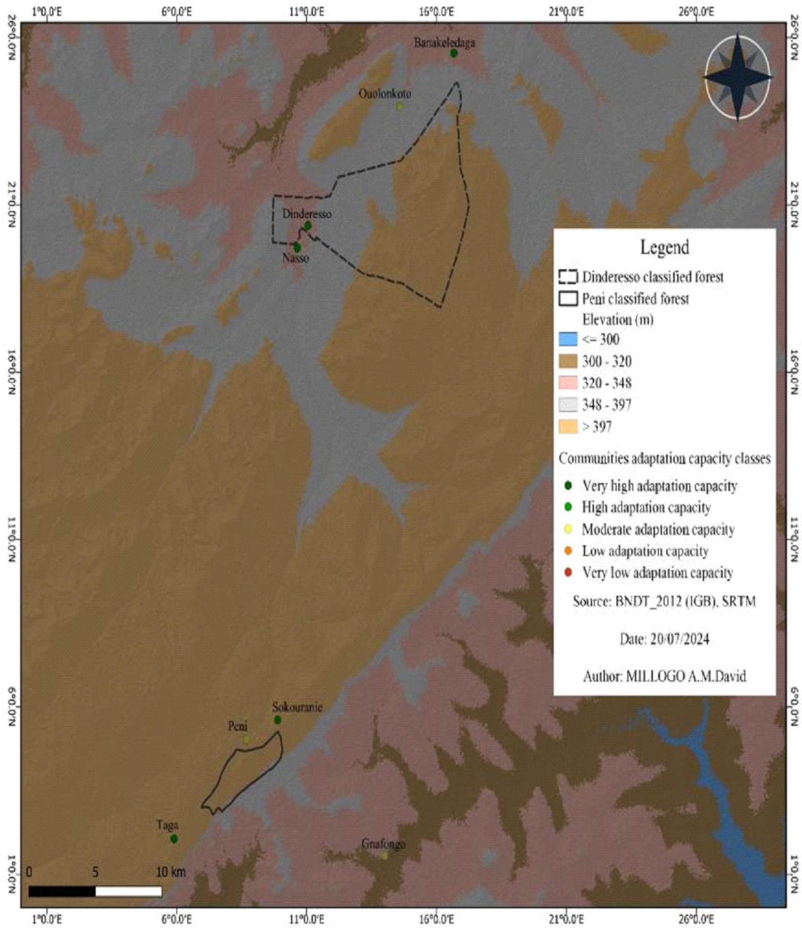


Figure 6: Dinderesso and Peni classified forest neighboring communities' adaptation capacities to forest provisioning ecosystem services degradation and loss.

3.5 Neighboring communities' vulnerability

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

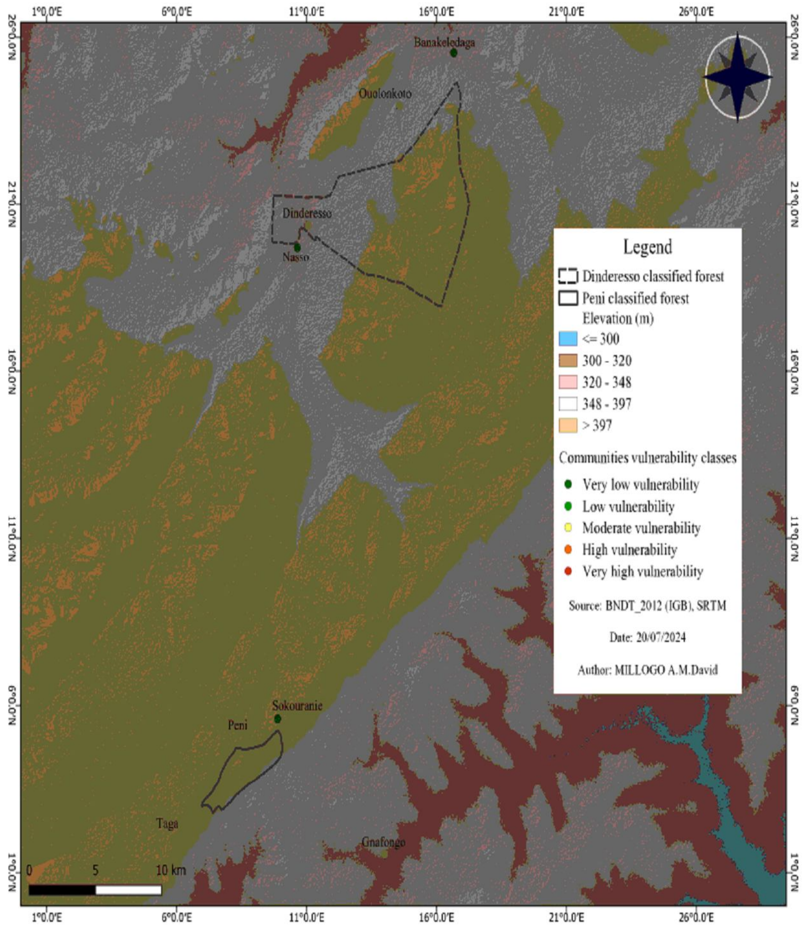


Figure 7: Dinderesso and Peni classified forest neighboring communities' vulnerability to climate variability and human activities

4 DISCUSSIONS

4.1 Neighboring communities' exposure to drought, rainfall, and temperature variability

The results of the current study showed that all the neighboring communities of the two forests experienced climate change variability through drought, rainfall, and temperature evolution during the last ten years. All the neighboring communities said they had experienced drought at least once during the last ten years. They also perceived changes in rainfall decreasing and temperature increasing during the last ten years. These results align with the research of [30], 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 [31]. Some research conducted in Bobo-Dioulasso, the province that hosted the current study area, predicted an increase in the temperature from 2012 to 2100 [32]. 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, communities experiences with climate change and variability, events, their well-being statute, traditional knowledge, soil type, vegetation, and occupation which could influence perception to exposure [33]–[36]. 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 [37], 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 [38], 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. Forest has contributed for a long to rural communities' food security in support of crops [2], [39], [40]. According to [41], 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 [17], [42]. 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 [43]. Overexploitation of forest provisioning ecosystem services contributes to its degradation [44]. 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, [45] 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 recognized 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 medicine tree, 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. Some 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 influence negatively or positively the dependence of households to fuel income [41]. Comparing the amount of forest provisioning ecosystem services sold by communities, [42] showed that some communities exploited and sold more forest provisioning ecosystem services than others. According to [46], the proximity of protected areas to urban cities contributes to forest area degradation. Interestingly, in environmental protection, [47] 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 level 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 subfactor 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 [48], [49], 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 [50], [51]. 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 [52]–[54]. 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 organizations. 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. In order 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, 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 [55]. 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 organization 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 [56] and [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. Even if they recognized 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 [58].

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. Some research has highlighted the differential vulnerability levels observed among communities [59], [60]. 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 organizations and neighboring communities committed to Dinderesso and Peni classified forest sustainability management.

5. Conclusion

The assessment of neighboring Dinderessso and Peni classified forest communities' vulnerability under drought, rainfall, temperature exposure, neighboring communities' activities sensitivity to forest provisioning ecosystem services, neighboring communities' adaptation capacity to forest provisioning ecosystem services degradation, loss impacts, allowed the identification of each community's current exposure, sensitivity, adaptation capacity, and vulnerability level. The results showed the differential vulnerability of neighboring communities ranging from low to moderate.

These results showed that neighboring communities are all but not similarly exposed to drought, rainfall, and temperature variability due to topography, altitude, and knowledge, which are some characteristics that communities use to express their exposure to drought. During the participatory exchanges with neighboring communities, they recognized that many of their activities might directly or indirectly affect forest provisioning ecosystem services. Also, being all neighboring communities, they do not have the same relationship with forest provisioning ecosystem services. To cope with threats to their livelihoods due to forest provisioning ecosystem services degradation and loss, neighboring communities' adaptation capacities improved over the years by all the stakeholders, which encompasses public government, private, and neighboring communities themselves, engaged in both Dinderesso and Peni classified forest restoration and neighboring communities livelihoods improvement throughout projects and common daily environment activities, was able to downplay the level of neighboring communities vulnerability which varies from low to moderate so non-critical so far. However, looking at firstly, the climate scenarios predicting increasing climate extreme events for the West African regions [5] and secondly, considering population growth with strong urbanization in progress, some efforts have to be put in place to ensure the best for Dinderesso and Peni classified forest as well as for their neighboring communities. For that, the current vulnerability framework of protected areas neighboring communities offers an opportunity for public and private organizations to easily and quickly assess before each investment in protected areas with their neighboring communities, the initial status of protected areas with their neighboring communities, to monitor the effects of their investments in protected areas with their neighboring communities to adjust these investments if needed, and also to appreciate at the end of their investment, the impacts. This tool can be used as an early warning tool for protected areas with their neighboring communities' sustainability management quality and disaster risk management in the protected areas domain with their neighboring communities.

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disclaimer (artificial intelligence)
Grammarly has been used to enhance the manuscript's grammar structure.

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