Exploring Wildfire Occurrence: Local Farmers' Perceptions and Adaptation Strategies in Central Côte d'Ivoire, West Africa

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Abstract

Wildfires are an important ecological threat in Côte d'Ivoire with the northern half the most affected zone. This study assessed farmers' perception of wildfire occurrence in the N'Zi River Watershed and compared this perception to remotely sensed fire data trends. To this end, 259 farmers were individually interviewed and 18 farmers were involved in three focus group discussions in three agro-ecological zones. A combination of descriptive statistics and regression analysis was used for data analysis. Results showed that 78.75% of farmers observed the upward trend in the annual wildfire activity identified by remote sensing data during 2001–2016. Most of the respondents identified hunting (65.83%), farm establishment (50%) and firebreaks establishment (46.67%) as main causes of wildfires. The perceived impacts of wildfires included immediate crop burning, crop growth delaying, mid-term post-fire crop destruction, destruction of material goods and loss of human life. Local population developed endogenous strategies to cope with this scourge. Amongst identified coping strategies, firebreaks establishment and maintenance around new clearings and farms and prohibition of fire-hunting during the dry season were highlighted. Therefore, policies and institutions that support local wildfires management initiatives must take advantage of the strong community knowledge and networks to strengthen their effectiveness and sustainability.

Keywords: Wildfire; local perception; adaptation strategies; hazard mitigation; N'Zi River Watershed

Introduction

Wildfires are a major type of ecological disturbance that significantly influence ecosystem dynamics and human livelihoods (Archibald et al., 2010). Globally, about 350 million hectares of vegetation are burnt every year with almost one half found in sub-Saharan Africa (FAO, 2007; Giglio et al., 2009; Humber et al., 2018). These wildfires disproportionately affect the world's most vulnerable people particularly poor rural communities that highly depend upon natural resources and the land for their livelihoods (Davies et al., 2018; Doerr & Santín, 2016). The majority of these wildfires are caused by human activities usually associated with land-

use practices and changes (Adouabou et al., 2004; Goldammer et al., 2002; Houinato et al., 2001; Kouassi & Ahoussi, 2010; Mbow, 2004).

In the tropics and particularly in Côte d'Ivoire, wildfires have been widely practised for various purposes for decades, in all regions of the country. They play an important role in forest ecosystem functions and carbon dynamics (Kull & Laris, 2009; Lehmann et al., 2014; Shlisky et al., 2009). Their dynamics in the landscape is one of the most addressed topics by the scientific community regarding phenomenon effects on all the components of the environment, in particular vegetation, fauna, soil, water and air (Aubréville, 1953, 2013; Louppe & Oliver, 2004; Louppe et al., 1995; N'Dri et al., 2012, 2014). Several authors reported wildfires as a climate-induced disturbance (Jolly et al., 2015; Kouassi et al., 2018; Laris, 2013). Moreover, climate change impacts are already being felt in several regions by increases in frequencies, intensities or sizes of wildfires and, therefore, in the extent of the damage (IPCC, 2014). In West Africa, these changes are happening quickly at the local level. In a status quo scenario, the temperature increase forecast is estimated to be 2.1°C by 2070 at the regional level and in Côte d'Ivoire (IPCC, 2014; World Bank, 2013, 2018). These forecasts, coupled with increased variability in precipitation, repeatedly cause uncontrolled wildfires that are difficult to control (World Bank, 2018). Also, some authors estimate that areas likely to burn could increase from 50% to more than 100% during this century, depending on the intensity of global warming (IPCC, 2014; World Bank, 2018). In areas already exposed to wildfires, the length of the fire season and the number of days with a high risk of wildfire are likely to increase due to longer rain-free periods (ThinkHazard, 2019; World Bank, 2013). In the face of these alarming changes and forecasts, prevention and control policies must be based on a good understanding of the factors that cause fires to start and their spread, as well as the human, environmental and socio-economic impacts caused by these wildfires.

In recent decades, the northern half of the country has experienced increasingly uncontrollable and devastating wildfires (SODEFOR, 2006). These wildfires caused damage to human and animal lives and activities and have a very high social and economic cost (Bigot, 2005; FAO, 2007). Indeed, the country experiences each year, around January and February, a peak of wildfires, which ravage hundreds of thousands of hectares of agricultural lands. For instance, during the dry season of 1982/1983, violent wildfires broke out, killing more than 100 people and causing severe agricultural and environmental damage (Goldammer, 2000; Goldammer & de Ronde, 2004). In the year 2016, wildfires ravaged more than 15,000 ha of croplands, 11,000 ha of forests, 200 huts in 10 villages and killed 17 people (MINEF, 2017). The financial loss linked to this damage was estimated at nearly 204 billion CFA francs (MINEF, 2017). Since the causes of these wildfires are dynamic and constantly fed by farming and farmers practices, farmers should have an appreciation of wildfire regime, trends and causes to enable them to cope with increasing incidences of wildfires in the agricultural landscapes (Amissah et al., 2011).

Remote sensing, due to its synoptic view, presents a unique opportunity to analyze the magnitude and the trends wildfires and identify the impacts of wildfires (Hawbaker et al., 2008). The advent of satellites has greatly contributed to the monitoring of wildfires in tropical and temperate countries. Indeed, several studies have shown the importance of remote sensing to measure the impacts of wildfires and their dynamics in tropical savannah of Brazil (Libonati et al., 2015; Mataveli et al., 2018; Moreira de Araújo & Ferreira, 2015; Moreira de Araújo et al., 2012), Africa (Andela & van der Werf, 2014; Archibald et al., 2010; Devineau et al., 2010; Kusangaya & Sithole, 2015), in the tropical zone (Van der Werf et al., 2008) and globally (Earl & Simmonds, 2018; Giglio et al., 2009). Several sensors are available to monitor active fires,

post-fire damages including fine, medium and coarse spatial resolution (FAO, 2002; Flasse et al., 2004). The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor, onboard of the Terra and Aqua satellites of the Earth Observing System (EOS) program, is one of the widely used remote sensing sensors due to its spatial and temporal resolution (Kaufman et al., 1998). The sensor is designed to provide measurements in global dynamics on a large scale, including changes in cloud cover, plant cover and phenology and processes occurring in the oceans, on land and in the lower atmosphere (Kaufman et al., 1998). This instrument is supplemented by the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor, aboard the Suomi-National Polar-Orbiting Partnership (Suomi-NPP) satellite to guarantee the continuity of data collection regarding the aging of EOS satellites (Terra and Aqua) and complete MODIS fire detections (Schroeder et al., 2014). As part of this study, data from the MODIS and VIIRS sensors, due to their spatial resolution (pixel size ~ 375–1,000 m) and temporal resolution (1–2 days), were used to monitor wildfires.

With regards to wildfire statistics, climate projections showing perpetual deterioration and regarding requirements of developing fire management strategies in a changing climate, it is important to characterize the spatio-temporal distribution of wildfires over several periods and understand perceptions of local people about wildfire regime in their environment and the prevention strategies adopted to cope with this scourge.

This study aims to analyze the understanding of farmers' perception of wildfire occurrence and the strategies developed by them to adapt and prevent wildfires in the N'Zi River Watershed in central Côte d'Ivoire. Hence, specific goals of this study include: (1) to assess the perception of local farmers to the occurrence of wildfires between 2001 and 2016, (2) to verify the farmers' perceptions by analyzing 16-year remote sensing data, (3) to assess the impacts of wildfire induced shocks on farmer's livelihoods and the environment, and (4) to identify ongoing prevention and mitigation strategies employed in response to the perceived wildfire impacts and hazards.

Material and methods

Study area

This study was undertaken in the N'Zi River Watershed (NRW), a sub-watershed of the Bandama River Watershed located in central Côte d'Ivoire. It is included in the rectangle defined between 3°46′ W and 5°24′ W longitude and 5°58′ N and 9°26′ N latitude. The region covers about 35,309 km^2 and the altitude ranged between less than 100 meters above sea level (m a.s.l.) in the south and more than 600 m a.s.l. in the north (Figure 1). The NRW occupies nearly 11% of the national territory and straddles 80 subdistricts (Kouassi et al., 2018). It covers the major climatic regions of Côte d'Ivoire. Three biomes are found in the NRW including forest ecosystems in the south, mosaic forest–savannah ecotones in the center and savannah ecosystems in the north (Eldin, 1971; Goula et al., 2006).

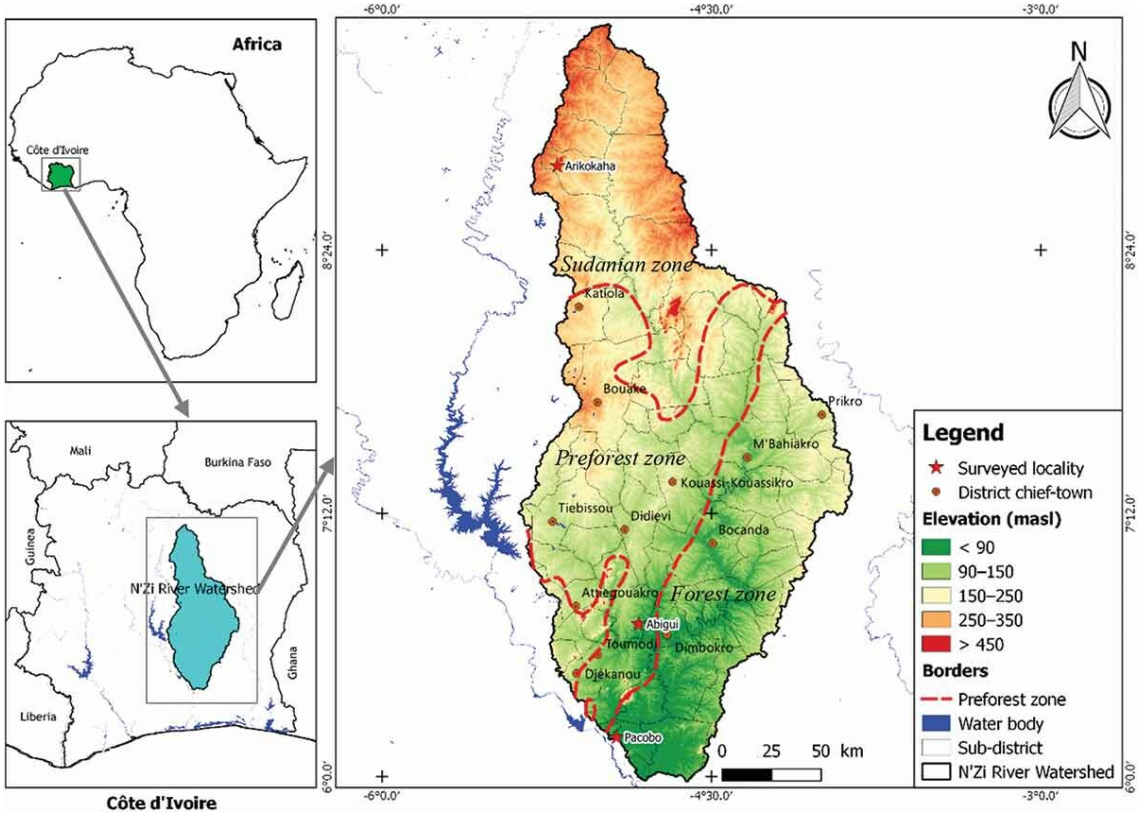

Figure 1. Map of the study area showing surveyed localities.

The region experiences a tropical wet and dry climate of *Aw* type in Köppen-Geiger climatic classification. In the forest zone, the climate is of equatorial transition climate (Guinean climate) type with annual rainfall between 1300 mm and 2400 mm (Goula et al., 2006). In this area, the vegetation is the dense moist forest with some remnant forests on the top of hills and in the classified forests (Guillaumet, 1971).

The pre-forest zone experiences an attenuated equatorial transition climate (Baoulean climate). The annual rainfall ranges between 1,500 mm and 2,200 mm. The vegetation is characterized by Guinean forest–savannah mosaic, with forest patches along rivers (Goula et al., 2006). The open forests are composed of trees whose crowns almost meet, below which the land and grass cover is very sparse. The wooded savannahs and open wooded savannahs are made up of trees or shrubs sparse with herbaceous species of Poaceae family (especially *Panicum* spp., *Loudetia arundinacea, L. simplex*, etc.) and elephant palm (*Borassus aethiopum*) stands, which are adversely affected by wildfires (Guillaumet, 1971). These two ecoregions have two dry seasons and two rainy seasons. The Sudanian zone is characterized by a dry tropical transition climate (Sudano-Guinean climate) with two seasons (Goula et al., 2006). The landscape is mainly composed of grassland and wooded grasslands. In this area, the herbaceous cover is composed of species of *Panicum* and *Pennisetum*, which are regularly affected by wildfires (Guillaumet, 1971).

The landscape is drained by the tributaries of N'Zi River and covered by fairly to moderately desaturated ferralitics soils, which are generally fertile and suitable for food crops and cash crops (Perraud, 1971).

The population of the NRW estimated at 1,834,623 inhabitants in 1998, increased to 2,866,836 inhabitants in 2014 and is distributed among 492,987 households (INS, 2014).

Wildfire trend

Spatial and temporal patterns of wildfires occurring in the area were assessed with a combination of MODIS MCD14DL active fire products with a spatial resolution of 1 km (Giglio et al., 2016) and VIIRS VNP14IMGTDL active fire products with a spatial resolution of 375 m (Schroeder et al., 2014) derived from the MODIS and VIIRS sensors, respectively. The MODIS is a sensor onboard of the Terra and Aqua satellites of the Earth Observing System (EOS) program of the National Aeronautical and Space Administration (NASA), launched in 1999 and 2002, respectively (Kaufman et al., 1998).

The MODIS MCD14DL Collection 6 and VIIRS VNP14IMGTDL products contain geographic coordinates, day of detection, brightness temperature, fire radiation power, and detection confidence level for all MODIS/VIIRS fire pixels. These data were produced by the University of Maryland and downloadable from the NASA LANCE FIRMS website (LANCE FIRMS, 2017a, 2017b).

In this study, we considered active fire data with a detection confidence level above 80% regarding field observations to avoid taking into account false detection of wildfires (Müller et al., 2013; Oliveras et al., 2014). The data were then pooled and sum values per month and year were computed to evaluate long-term trends of wildfire occurrence.

Local wildfire data spanning from 2001 to 2016 were graphed to visualize the pyrologic environment that the people in each ecoregion have recently been exposed to. The magnitude, the direction and the significance of the trends of wildfire occurrence over the past 16 years (2001–2016) were determined using regression analysis. The regression equation was defined

as: $Y_i=\beta_0+\beta_1 X_i+\varepsilon$ (1)

Where

- Y is the total annual wildfire occurrence;
- X is the time measure in years;
- β_0 is the constant term (intercept);
- β_1 is the coefficient of the independent variable (known as the slope and gives the rate of change of the dependent variable);
- $\varepsilon \sim N(0, \sigma^2)$.

It was hypothesized that there is no trend in wildfire activity over time (null hypothesis). The trend of time series depends on the sign of β_1, where positive value indicated an upward trend and negative values showed a downward trend.

Also, we estimated the fire anomaly (FA) using the standardized anomaly equation (Wilks, 2005):

$$FA_i = \frac{\overline{X}_m - \overline{X_m}}{\sigma(\overline{X}_m)} \quad (2)$$

Where:

- X is the studied variable (number of wildfires);
- $\overline{X}_m$ is the spatial average value for each year *m;*
- $\overline{X_m}$ is the mean of $\overline{X}_m$ over the same year over the multi-year dataset;
- $\sigma\overline{X}_m$ is the standard deviation of $\overline{X}_m$ for the time series over the same period.

Positive anomalies indicate that wildfire occurrence for the specific year is higher than the mean (high activity), while negative anomalies show that wildfire activity is lower than the mean values (low activity).

Data were computed and graphed using R software (R Core Team, 2019).

Farmers' perception

This research focused on small-holder farmers' households perceptions of wildfire occurrence from 2001 to 2016, used focus group discussions (FGDs), household interviews with the members from a statistically selected sample of households (n = 259), and active fire data analysis. Farmers' prior informed consent was obtained and the anonymity of the study was shared with participants before undertaking the household survey and the FGD.

Sampling technique

In this study, we used a stratified purposive sampling technique to select localities and households. The stratification was based on the phytogeographical location (ecoregion) and the administrative districts (sub-prefectures and localities). Three ecoregions were identified for the first stratum (forest, preforest and Sudanian zones). The second stratum was composed of sub-prefectures while the third stratum is concerned localities having more than 1,200 inhabitants identified as census districts (INS, 2014). For household data collection, the localities of Pacobo, Abigui and Arikokaha were purposively selected in the forest, preforest and Sudanian zones, respectively.

The sample size was calculated at the 95% confidence interval, a margin of error of 5% and a proportion of 50% (Ross et al., 2002).

For this study, only agricultural households were surveyed. A "household" is defined as a farm family unit consisting of a group of interrelated people living together, sharing the same dwelling house, working on the family farm, making farm-level decisions (including adaptation) and pooling their labor to manage their farm under the prime leadership of the household head (Debela et al., 2015; Solomon et al., 2007).

Interviews

Interviews were held with the heads of farm households. They were conducted in January 2017 in two-steps, a field pretest and effective data collection. Enumerators were hired to conduct the household interviews during the field research. Before the implementation of the interviews, enumerators received field training on the survey instruments and ethical considerations of this research. Each survey questionnaire contained several questions and took

an average of an hour and a half interview time. Data were collected using Open Data Kit (ODK) Collect application installed on Android tablets.

The household survey questionnaire was designed after a review of the literature about farmer perception of wildfires activity and its impacts. The questionnaire was then pretested in the study area to identify potential unclear questions and make sure that the questions and methods were tailored to local circumstances. The questionnaire was revised based on feedback from the pilot survey.

Both qualitative and quantitative techniques were utilized for data analysis. Basic descriptive statistics, such as mean, frequency, percentage and count were used to provide insights into farmers' perceptions of wildfire occurrence and variability. The chi-square test was used to test the significance of differences between responses. The analysis was carried out using the package *questionr* (Barnier et al., 2017) of R software.

Focus group discussions

We used purposive sampling based on theoretical saturation for the FDGs in this study (Guest et al., 2006). This technique allows for gathering information from specific types of people. Only farmers (men and women) over 40 years old who consented were eligible to attend to these FGDs. To implement this technique, public consultations with the heads of different ethnic groups, youth and women presidents and rural development officers were conducted for the establishment of a list of people following these criteria: (i) have lived continuously between 15–20 years in the community, (ii) have a good knowledge of agricultural practices, (iii) have a good knowledge of local and improved strategies against wildfires and climate change, (iv) be available on the day and the time of completion of the focus group.

In each village, there were six participants (three men and three women) in the FGDs. In total, three FGDs were held involving 18 farmers composed of community leaders, youth and women presidents. Key data collected were on people's perceptions of wildfire occurrence and perceived impacts on their livelihoods, households' and community response strategies.

Qualitative information collected through qualitative techniques was used to describe farmer's perceptions of long-term wildfire occurrence as well as various prevention measures used.

Results

Wildfire trends

In the last 16 years, 19,156 wildfires were detected in the NRW. Wildfires showed a strong seasonal dependence within the NRW and this seasonality was almost similar in all the ecoregions (Figure 2). Vegetation fires were more frequent during the dry season in all ecoregions and more moderate until the start of the rainy season (March-April). In the NRW, the maximum number of wildfires was generally reached from December to January. Wildfire occurrence began in November and faded in April. The number of wildfires increased rapidly in December, reaching a peak in January. During February-April, the number of wildfires substantially decreased to achieve the lowest values in April. Thus, the fire season lasted six months (November to April) in the watershed and five months (November to March) in the preforest and Sudanian zones.

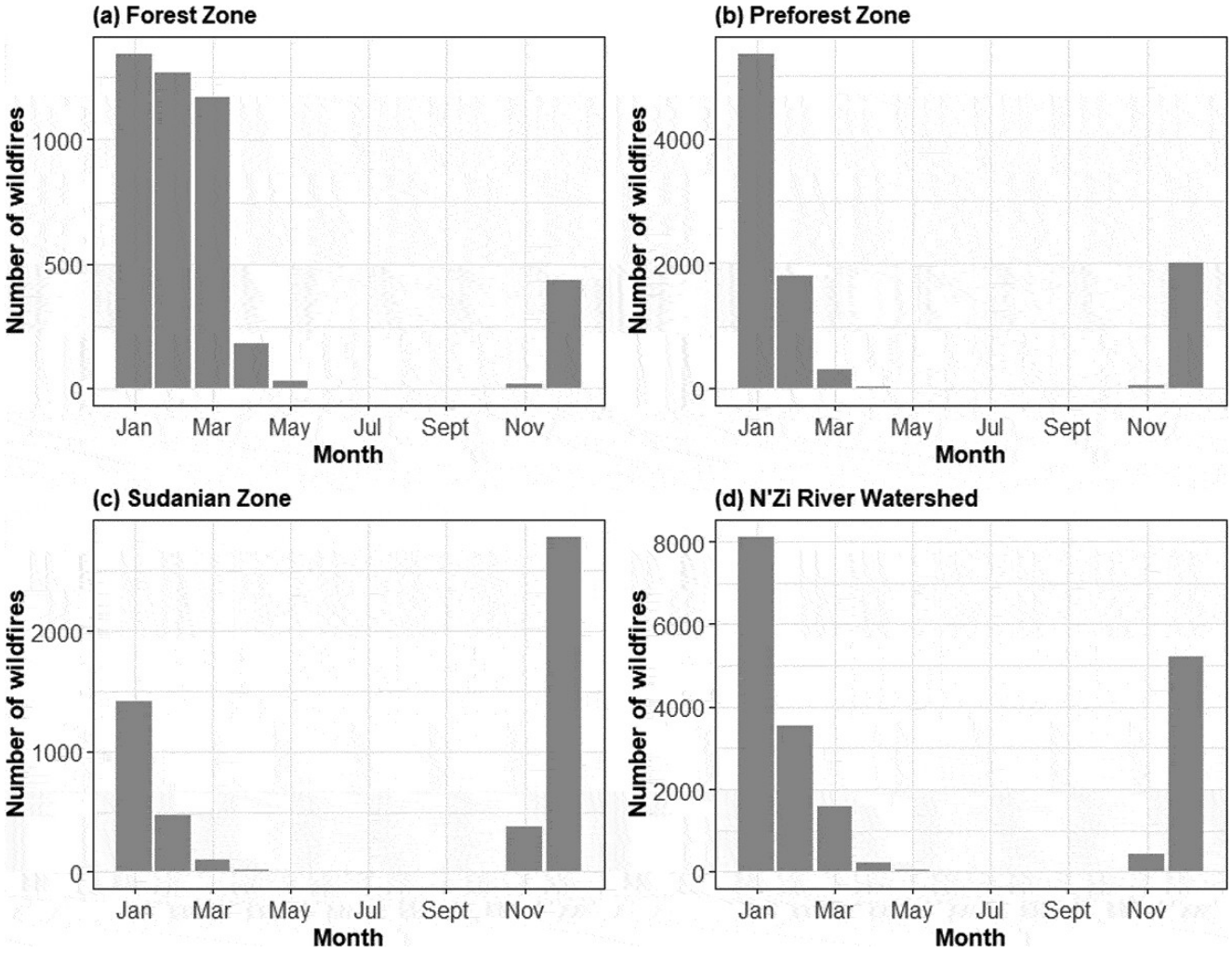

Figure 2. Monthly occurrence of wildfires in the (a) forest zone, (b) preforest zone, (c) Sudanian zone and (d) the whole NRW.

In the NRW, the highest values of wildfire occurrence were recorded in the preforest zone. December was the critical month, with 8,116 wildfires detected (42.4%). Besides, the month of January recorded 1,344 wildfires and 5,353 wildfires for the forest and preforest zones, respectively.

At ecoregion level, the number of wildfires was estimated at 4,443 wildfires, 9,536 wildfires and 5,177 wildfires for the forest, pre-forest and Sudanian zones, respectively.

Figures 3 and 4 present the annual occurrence of wildfires (NF) and fire anomalies (FA) in the study area, respectively. The annual number of wildfires varied enormously during the studied period. In 2008, the greatest number of wildfires was observed in the preforest (NF = 1,161 wildfires; FA = 2.57) and the NRW (NF = 1,949 wildfires; FA = 2.34) except the forest zone (NF = 625 wildfires; FA = 2.25) and the Sudanian zone (NF = 565 wildfires; FA = 1.7) where the highest peak of wildfires was observed in 2016 and 2002/2005, respectively. On the other hand, the lowest values of wildfire occurrence were recorded in 2001 in the preforest zone (NF = 217 wildfires; FA = 2.25), the Sudanian zone (NF = 126 wildfires; FA = 2.25) and the whole NRW (NF = 453 wildfires; FA = 2.25) except the forest zone which presented the lowest quantities of wildfires in 2009 (NF = 74 wildfires; FA = 2.25).

The linear trend curves of fire anomalies (in red) showed that the forest zone (β_{FA}= 0.10, R = 0.45, p = .08), preforest zone (β_{FA} = 0.06, R = 0.28, p = .29) and the NRW (β_{FA} = 0.04, R = 0.17, p = .52) revealed a non-significant upward trend, while the Sudanian zone (β_{FA} = – 0.11, R = – 0.54, p = .03) presented a significant downward trend (Figure 4). Similar trends were highlighted in Figure 3.

Socioeconomic and demographic characteristics of sampled households

Among the 259 surveyed farmers, 33.2% of the respondents were in the forest zone, 32.82% in the preforest zone and 33.98% in the Sudanian zone. These results showed the equipollence in each ecoregion. Highly significant differences (p < .001) were found between the social characteristics of households and ecoregions (Table A2).

Most respondents (81.85%) were men, between the ages of 22 and 84 with an average of 47.9 years. Consequently, the surveyed population was predominantly adults (71.88%) and natives (88.8%). Most of the respondents were married (82.63%). These farmers were mainly illiterate (43.63%) or have only elementary education (35.52%). Finally, sampled farmers were Christian (52.9%), Muslim (11.58%) or did not practice any religion (28.57%).

The results also indicated that the age range of farmers resident in the study area was from 2 years to 84 years, with an average age of 32.72 years. The household size ranged from 1 person to 15 persons, with an average size of 5.94 persons. All the sampled households (100%) were engaged in farming activities and agricultural activities remained the main source of income for the interviewed households. The majority of the respondents grew cocoa (41.31%) and cashew (45.95%) as cash crops, and yam (69.98%) and cassava (40.54%) as food crops. Cocoa was mainly grown in the forest and preforest zones while cashew was cultivated in the preforest and Sudanian zones. Major food crops were cultivated in both ecoregions at almost the same rate. On the one hand, cash crops size varied from 0.5 to 8 hectares, with an average of 3.32 hectares for cocoa while cashew plantation size ranged from 1 hectare to 32 hectares with an average of 4.14 hectares. On the other hand, yam farm size oscillated between 0.25 and

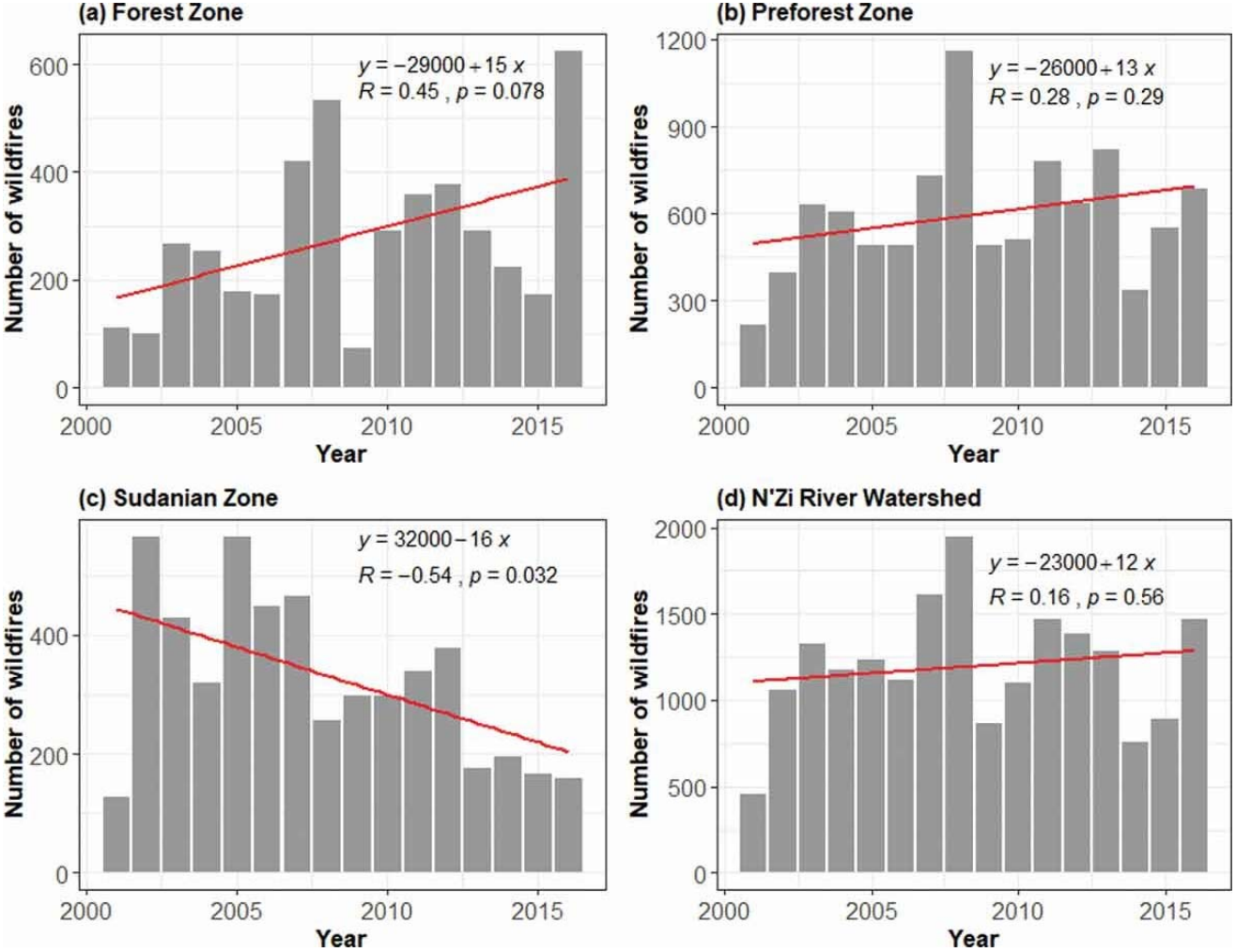

Figure 3. Annual occurrence of wildfires in the (a) forest zone, (b) preforest zone, (c) Sudanian zone and (d) the whole NRW.

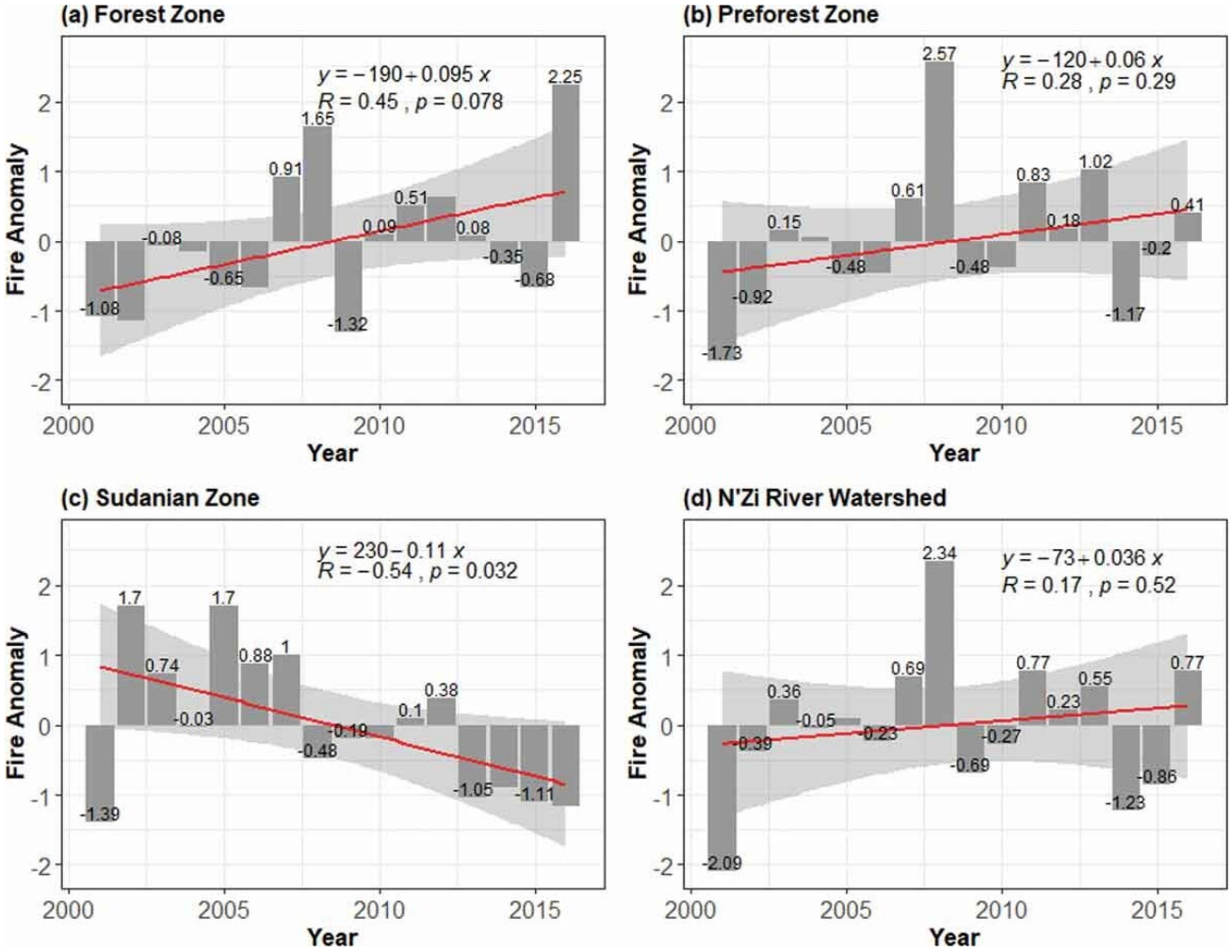

Figure 4. Annual Fire Anomaly in the (a) forest zone, (b) preforest zone, (c) Sudanese zone and (d) the whole NRW.

3 hectares with an average of 1.98 hectares while cassava farm size extended from 0.25 to 4 hectares with an average of 0.97 hectares.

Table 1. Perceptions of wildfire activity and dynamics

		Proportion (%)			
Perceptions attributes		FZ	PFZ	SZ	NRW
Wildfire activity	No	10.47	0	11.36	7.34
	Yes	89.53	100	88.64	92.66
Wildfire trends	Increased	98.7	98.82	37.18	78.75
	Decreased	1.3	1.18	44.87	15.42
	No change	0	0	11.54	3.75
	Do not know	0	0	6.41	2.08
Wildfire recurrence and intensity	No change	0	1.18	1.28	0.83
	Rare and low	0	0	1.28	0.42
	Rare and violent	98.7	1.18	2.56	32.92
	Recurrent and low	0	3.53	1.28	1.67
	Recurrent and violent	1.3	94.12	91.03	63.33
	Do not know	0	0	2.56	0.83
Wildfire frequency	Once every year	0	96.47	80.77	60.42
	Twice every year	46.75	2.35	11.54	19.58
	Three times a year	2.6	1.18	0	1.25
	Do not know	50.65	0	7.69	18.75

FZ: Forest zone; PFZ: Preforest zone; SZ: Sudanian zone and NRW: N'Zi River Watershed

Perceptions of wildfire dynamics

Farmers' perception of the evolution of wildfires in the study area is presented in Table 1. The results showed that most of the farmers (92.66%) experienced wildfires in the studied watershed during the last 15 years. The number of these wildfires had increased over the past 15 years, according to 78.75% of the surveyed farmers. However, 15.42% of the population believed that this phenomenon had decreased in the study area. Interviewed people who noted a decrease in wildfires were found mainly in the Sudanese zone.

On the intensity of the wildfires, most of the respondents (63.33%) revealed that wildfires were recurrent and violent in the NRW. On the other hand, 32.92% of the interviewees noted that wildfires were rare and violent in the landscape.

In terms of wildfires frequency, 60.42% of the farmers believed that wildfires occurred once a year in the region. However, some farmers claimed that wildfires occurred twice a year (19.58%) or three times a year (1.25%) in their localities while other farmers (18.75%) were unable to assess wildfires frequency in the landscape.

Local communities revealed that most wildfire activities occurred in January and February according to 87.9% and 87.09% of the respondents. Accordingly, the fire season lasted from December to February (Table A3).

Several indicators of high wildfire risk exist in the landscape (Table A4). According to respondents, the indicators of high wildfire risk were high sun intensity period (65.42%), extended dry season (51.25%) and browning of grasses and bushes (40.83%). About 32.92% of the interviewees revealed wildfire risk was high when trees shed their leaves.

The perceived causes assigned by farmers to these wildfires were diverse with mainly anthropogenic sources (Table 2). The main causes of wildfires were hunting (65.83%),

agricultural plots establishment (50%), firebreaks establishment (46.67%), sabotage or revenge acts (30%), charcoal production (22.5%), cooking at the field (16.25%), unextinguished cigarette butts (10.42%) and palm wine extraction (10%). These last two causes were mainly observed in the forest zone.

Table 2. Perceived causes of wildfires in the landscape

	Proportion (%)			
Causes	FZ	PFZ	SZ	NRW
Hunting	87.01	90.59	17.95	65.83
Agricultural plots establishment	59.74	84.71	2.56	50
Firebreak establishment	15.58	67.06	55.13	46.67
Sabotage or revenge	40.26	1.18	51.28	30
Charcoal production	11.69	48.24	5.13	22.5
Cooking at the field	3.9	42.35	0	16.25
Unextinguished cigarette butts throw	31.17	0	1.28	10.42
Palm wine extraction	28.57	2.35	0	10
Crop residues burning	7.79	1.18	1.28	3.33
Pasture renewal	0	0	5.13	1.67
Do not know	0	0	5.13	1.67
Other	5.19	0	37.18	13.75

FZ: Forest zone; PFZ: Preforest zone; SZ: Sudanian zone and NRW: N'Zi River Watershed

Impacts of wildfires on communities

The impacts of wildfires on rural communities were diverse at the landscape level including impact on cropping systems, settlements and human lives. In the NRW, 64.58% of the interlocutors was affected at the agricultural level by wildfires during the last 15 years. The impacts of wildfires on crops are multiple. Table 3highlights that the major impacts of wildfires on crops were immediate crop burning (75.68%), crop growth delays (75.29%) and crops destruction a few weeks after wildfires (54.83%).

Table 3. Perceived impacts of wildfires on crops in the NRW

	Proportion (%)			
Perceived impacts on crops	FZ	PFZ	SZ	NRW
Immediate crops burning	95.35	84.71	47.73	75.68
Crop growth delays	73.26	81.18	71.59	75.29
Post-fire crop destruction	95.35	52.94	17.05	54.83
Do not know	0	0	26.14	8.88
Other	2.33	0	3.41	1.93

FZ: Forest zone; PFZ: Preforest zone; SZ: Sudanian zone and NRW: N'Zi River Watershed

Several crops were affected by wildfires in the landscape (Table A5). Interviewed farmers revealed that cashew (45.81%) with an average size of 2.51 hectares, and cocoa (38.71%) with an average size of 1.39 hectares were the most impacted crops in the studied area.

Only 2.5% of the population declared that wildfires affected their facilities and homes. The damage suffered by this population was the destruction of material goods including housing and other goods (100%) and loss of human life (16.67%).

Strategies against wildfire hazards

Local people took action to mitigate, prevent or reduce wildfires hazards and impacts registered in their environment. Table 4 presents wildfires prevention strategies developed by farmers in the study area.

Table 4. Wildfires prevention strategies developed in the landscape

	Proportion (%)			
Wildfire prevention measures	FZ	PFZ	SZ	NRW
Firebreaks establishment around new clearings before burning	37.21	97.65	90.91	75.29
Firebreaks construction and maintenance around farms before the dry period	12.79	98.82	88.64	66.8
Prohibition of fire-hunting in the dry season	29.07	2.35	0	10.42
Wildfire alert and awareness in December-January	18.6	4.71	2.27	8.49
Firebreaks construction around forests and fallows during the dry season	0	5.88	18.18	8.11
Awareness through griots	22.09	0	0	7.34
No action	27.91	0	0	9.27
Do not know	1.16	0	4.55	1.93
Other	10.46	0	7.95	6.14

FZ: Forest zone; PFZ: Preforest zone; SZ: Sudanian zone and NRW: N'Zi River Watershed

The findings of this study showed that the majority of farmers (75.3%) claimed to establish firebreaks around new clearings before burning to avoid uncontrolled agricultural wildfires. Other farmers reported firebreaks construction and maintenance around farms before the dry season (66.8%), while 10.4% of respondents prohibited hunting with fire during the dry season in their locality. Also, some interviewees believed that the measures to prevent wildfires and their spread were firebreaks establishment around forests and fallows during the dry season (8.1%), awareness-raising and warning announcements during the dry period (8.5%) or awareness by griots (7.3%).

Facing wildfires impacts, farmers received information and awareness in the landscape (Table A6). These farmers acknowledged that they received awareness through television programs (79.17%) and radio programs (65.62%). Nonetheless, most of the respondents suggested receiving awareness through meetings with rural authorities or communities (83.01%) and education campaigns with forestry administration (77.61%).

Discussion

Wildfire trends

As part of this research, active fire data were employed in wildfires regime and trend monitoring. Research findings showed that wildfire density was maximum during the hottest months (December-January) in the NRW. Indeed, wildfire activity is prominent during the dry season when climatic factors favor the flammability of vegetation and the spread of wildfire mainly due to the presence of the Harmattan (Oloukoi et al., 2014). Fire season depends on vegetation humidity, late and very late wildfires burn more intensely (low vegetation moisture content) and tend to cause more damage than early wildfires. These findings confirm observations of N'Dri et al. (2018), Nielsen and Rasmussen (2001), and Govender et al. (2006).

The pre-forest area was the most fire-affected ecoregion in the landscape. This finding could be explained by the landscape ecology (ecological transition zone made up of a mixture of savannah and forests known as ecotone), vegetation types, land uses and fire-based hunting

practices adopted by local people in this ecoregion. Several works underline similar observations (Bruzon, 1994; Etienne, 1971; Mbow et al., 2004; Nielsen & Rasmussen, 2001; Trollope et al., 2004).

The analysis of the intra-annual wildfire regime showed that the number of wildfires increased during the period 2002–2008 in the study area. These observations could be explained by the socio-political crisis experienced by Côte d'Ivoire between 2002 and 2010 that weakened the forest administration (funding withdrawal, lack of monitoring and governance). This situation has led to a softening of awareness and wildfires fighting policy at the local level. These observations are close to those of Kull (2002) and Tabor et al. (2017) who noted that political instability led to unusual practices in fire uses (protests, land disputes, etc.) that increased damages caused by the wildfires in Madagascar. Besides, this situation could be explained by an increase of demographic pressure leading to a greater number of wildfires due to poaching and conversion of savannahs to agricultural lands such as rubber and cashew farms establishment in savannah ecosystems (Govender et al., 2006).

Also, the return of investors in conservation activities funding and the implementation of initiatives such as the REDD+ mechanism since 2011 could explain this decrease in wildfire activity in this period. In Madagascar, Tabor et al. (2017) showed a very strong correlation between the increase in investments in conservation or reforestation and the significant reduction in wildfires.

The findings indicate that a significant number of wildfires with positive fire anomalies were recorded in the years 2007, 2008 and 2016. These observations could be due to climatic phenomena El Niño – La Niña which effects were among the most extreme during these periods (Fuller & Murphy, 2006; Moore et al., 2017; Null, 2018). The recurrence of these climatic phenomena increases the risk, the spread and the destruction caused by wildfires, which are increasingly less controllable on a global scale.

Our results underline an upward trend in the occurrence of wildfires in the NRW. A recent study in the NRW showed a decreasing trend in fire occurrence in the NRW using MODIS active fire data and Mann-Kendall tests (Kouassi et al., 2018). Several studies conducted in sub-Saharan Africa in recent decades have observed downward trends in the number of wildfires and burned areas (Dwomoh & Wimberly, 2017; Giglio et al., 2013; N'Datchoh et al., 2015). Andela et al. (2017) showed a significant downward trend in the number of wildfires, and burnt areas size in Africa between 2003 and 2015 using MODIS products. The increase in wildfire activity could be the result of climate change and variability experienced in the region (Kouassi et al., 2010).

Farmers perceptions

The results of this study showed that local communities also perceived wildfires activity in their landscape once every year. Farmers believe that the number of wildfires has increased in the surveyed localities and fire season extended from December-February. These observations substantiated the remotely sensed data analysis, which has shown an upward trend in recent decades. Also, the population in the Sudanian zone (44.87%) identified a significant downward trend. This similarity between perception and remote sensing data can translate the perception of the degree of exposure and the major damages caused by wildfires.

The causes assigned by farmers to these wildfires were diverse and mainly anthropogenic, including hunting and farms establishment. These results confirmed the observations of Bruzon (1994) and Fournier et al. (2014) who noted that hunting and the preparation of agricultural land are the main causes of bush fires in Burkina Faso and Côte d'Ivoire, respectively. Goldammer and de Ronde (2004) have shown that more than 10% of wildfires originate from fires that are poorly controlled during firebreaks establishment inside and around forest plantations. The poor control of wildfires is due to the lack of adequate training of personnel in charge of forestry work. Also, some farmers found that discarded cigarette butts were a cause of wildfires. Several studies showed evidence that unextinguished cigarette butts thrown by smokers can ignite wildfires (Butry et al., 2014; FRNSW, 2020; Marcano, 1997).

The impacts of wildfires, mainly from anthropo-climatic sources, caused severe damages on crops, resulting in immediate crops burning, loss of crops and delaying plants growth while at the level of housing, wildfires cause loss of human life and destruction of material goods. These findings were similar to those of Doerr and Santín (2016) and Appiah et al. (2010) who have shown that wildfires have significantly damaged crops and destroyed many tree plants and young trees planted at the start of farms.

The results of this study showed that farmers have a perception in line with current wildfire trends in the landscape. They are adopting measures to cope with and adapt to these observed changes. These prevention strategies are all linked to modern techniques as well as to the endogenous knowledge of rural populations. To prevent the impacts of wildfires, farmers created firebreaks around agricultural plantations and new clearings before burning and prohibit the use of fire for hunting. The results of this study confirmed the results presented in other studies on fire management (Amissah et al., 2011; Appiah et al., 2010; Fournier et al., 2014).

Conclusions

The current study investigated farmers' perceptions about wildfire occurrence in the NRW and compared this feedback to remotely sensed data of the last two decades.

Firstly, the wildfire regime analysis showed that the number of wildfires follows an upward trend. Wildfires occur more frequently within the NRW during the dry season and the regime differs depending on the ecoregions. The pre-forest zone was the most affected by wildfires in the NRW. Wildfires regime revealed that January had the highest peaks of wildfires and 2008 had the highest number of fires.

Secondly, the household survey showed that local farmers have a good perception of wildfires regime and variability. This perception corresponds in the majority of cases with the analysis of satellite data. However, perceptions varied according to the ecoregions and fit with scientific measurement. At the watershed scale, various mitigation and adaptation strategies have been adopted in response to the observed wildfires risks and hazards. The perceptions and adaptation strategies adopted are linked by an interdependent relationship in which the knowledge and shocks observed play an important role.

The results of this study can be used as basis and benchmarks for decision-making to reduce local people's vulnerability of current and future wildfires hazards and identify the strategies to be upscale at the national level in the framework of wildfires prevention and mitigation initiatives.

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Availability of data

The dataset generated and analysed during the current study is available in the Mendeley repository: [https://data.mendeley.com/datasets/mvttmyrcz7/2].

Conflicts of Interest

The authors declare no conflict of interest.

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