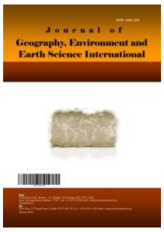

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Mapping of Burnt surfaces in the Context of Protected Areas in the Sudanian Savannahs of Northern Cameroon: Contribution of Time Series of Sentinel-2 Images

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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

In Africa, bushfires are common practices in savannah regions. Their impact, is the subject of many scientific debates. The protected areas, of North Cameroon are subjected to ambivalent effects of these fires. Using high-resolution remote sensing data, this work aims at assessing burned areas at the interannual and intraannual scale in order to explain the complex environmental dynamics of landscapes, to contribute to fire management in a context of protected areas. To achieve this, time series of sentinel-2 images from the Multi Spectral Instrument from the year 2015-2020 have been used. By the unitemporal and multitemporal methods, the development of spectral indices has made it possible to locate the burned surfaces and to determine the periods of the fires. Observations and field surveys aimed to understand the factors of fires using, their typology as well as the roles of the actors. The findings show that each spectral index has its own ability to detect burnt surfaces: The NDVI can detect fires only at the start of the dry season, the SAVI is suitable for

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identifying intermediate and late fires, while the NBR is best suited for separating burnt and unburnt surfaces throughout the season, regardless of the method employed. Depending on their periods of occurrence, the fires spread more in parks with a fairly extensive grass cover compared to overexploited ordinary areas. They then depend on socio-environmental factors, namely the state of land used, the continuity of the herbaceous cover and the social practices in place. The mapping and monitoring of burned surfaces by remote sensing therefore constitute a tool and a method for diagnosing the state of the herbaceous plant cover and for managing natural resources.

Keywords: Bushfires; burnt surfaces; remote sensing; spectral indices; protected area; Sudanian savannahs.

1. INTRODUCTION

African savannahs are the most actively affected areas by bushfires that pass through them each year [1]. An ancient and common practice in societies since the Neolithic period [2], bushfires are considered as an integral part of the Sudanian savannahs [3]: The Sahelian grass cover being discontinued enough to facilitate its extension, while dry periods in the Guinean savannahs are quite limited.

However, considering the terms of its use, fires are known for their ambivalent effects on the environment; particularly on the plant component. From an ecological standpoint, they are structuring factors of savannah landscapes through the maintenance of a relative balance between the ligneous layer and the herbaceous layer [4]. Moreover, their usefulness for populations is undeniable, in that, they fulfill several functions such as: Cleaning fields, regenerating pastures, hunting or rituals [5]. Conversely, fires are perceived as a factor of disruption and destruction of ecosystems, thereby representing an environmental constraint [1 ;6]. This is why colonial policies, within the framework of the defense of spaces and on the basis of these forest objectives, initiated the banning of fires in many regions in Africa. These prohibitions have been generalized both in the savannas and in the forests, especially in the context of a protected areas. Whereas, the methods of use and practice of fires are characterized by the period of their passage. These modalities define their typologies (late fires, early fires), their interannual and intraannual frequencies. This phenomenon makes it possible to distinguish “catastrophic fires” from “useful fires” in the savannas [1]. It is also well known that on an interannual scale, early fires areless devastating for vegetation and easily controllable on its spatial influence compared to late fires [7]. But it favors the increase of woody species through the phenomenon of undergrowth, while the late fires maintain the grass tree balance better in the long run.

In the Sudanian savannahs of Cameroon, the cultural power surrounding the use of fires and the pressure on space and plant resources complicate the management of protected areas. The National Parks of Benue, Bouba N'djidda and Faro, private domains of the State, protected areas whose management is the result of a set of planned and coordinated institutional actions, are affected by uncontrolled fires. The actors (those who set the fires and who profit from it or not) are clandestine and diversified. In this context, developing a methodology for carrying out spatio-temporal monitoring of burnt areas in order to provide detailed and reliable information on the practice and use of fires becomes a priority [8]. This is to contribute to the development of management strategies for protected areas in Cameroon whose threats are increasingly worrying.

To do this, remote sensing is a fairly widespread technique in the mapping of land use and burned areas. Satellite images make it possible for a geographical reading of fires by offering the possibility of measuring and monitoring fires activities and vegetation cover on a spatio-temporal scale [2]. Three fields of research can be explored within the framework of studies on bushfires. These are: Risk prevention, upstream of the fire phenomenon; detection of active fires and their regimes in relation to land use [9,10] and mapping of burnt areas for damage estimation and post-fires rehabilitation [11]. In the context of a geographical reading of the extension of the fires in relation to the dynamics of the vegetation, the burnt areas compared to the active fires data constitute a better source of information [9]. This research is focused on the mapping of burnt surfaces by favoring grass resources, an essential component of fuel in savannahs.

Considering their stakes, bushfires would be both an environmental management tool and also an environmental constraint. Moreover, their control escape from both the populations and the authorities. The regulatory provisions governing their use prove to be obsolete when they are applied. This obsolescence can be explained by a lack of decision-making tools, in particular updated GIS (Geographic Information Systems) databases relating to fires and land occupation or use. This work therefore aims at developping a cartographic method for monitoring bushfires in savannah ecosystems ; then to carry out a geographical reading of the extension of the fires, in a context of anthropogenic pressure in order to contribute to the development and management of protected areas.

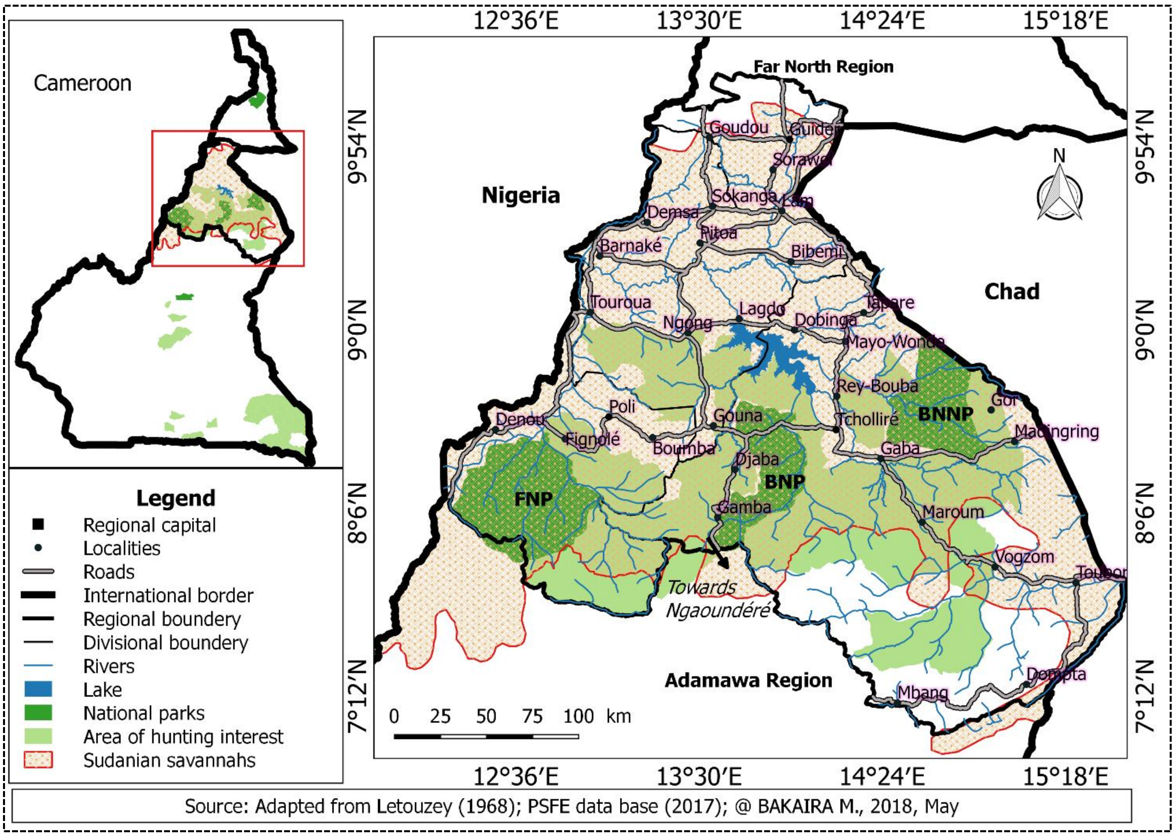
2. MATERIALS AND METHODS

2.1 The Study Area

The area chosen for this study is the Sudanian savannah area of northern Cameroon. Inaccuracies concerning the delimitation of this zone are reported in the literature. This ambiguity stems from the fact that it is both a climatic and also a phytogeographic zone [12]. Nevertheless, Letouzey [13] proposes a phytogeographic delimitation (Fig. 1).

This zone covers a wide strip which is interposed between the zone of thorny Sahelian steppes with which the Sudanian high altitude groups of the Mandara Mountains are associated in the North (10°10 N), and the Sudano-Guinean savannahs of the highlands from Adamawa region to the South. The southern limit here corresponds to what Boutrais [12] calls "the southern limit of the Sudanian zone in the broad sense", defined by rainfall in excess of approximately 1000 mm/year and which extends from the latitude 07°10' North.

Indeed, the steppe formations are established in the North as the abundance and duration of rainfall decrease. In its physiognomy, the continuous herbaceous cover gradually loses its continuity, while shrubby thorny formations are gradually established. However, a boundary juxtaposition is imposed by the intrusion



Source: Adapted from Letouzey (1968); PSFE data base (2017); @ BAKAIRA M., 2018, May

Fig. 1. Study area 's location

of species on the fringes on either side of the northern and southern boundaries. This makes it difficult to materialize this zone with exact boundaries between the steppe to thorny formations in the North and the Guinean savannahs in the South. Boutrais [12] specifies that the distribution of the rains, their duration and their quantity control the rhythm of growth of the herbaceous cover, but this limit does not always correspond and especially not necessarily to that of the woody ones.

However, the apparent monotony of the plant cover of the Sudanian savannas hides a large number of plant formations. The ligneous stratum is dominated by shrubby savannas with *Terminalia laxiflora*, and *Crossopteryx febrifuga*; savannas with trees of *Burkea africana* and *Afzelia africana*; wooded savannahs with *Isoberlinia doka* and *Opilia amantacea*, sparse forests with *Pterocarpus lucens* and gallery forests with *Diospyros mespiliformis* and *Anogeissus leiocarpus* which border the waterways of the region [14]. The lower stratum of these savannahs is composed of perennial and annual grasses with a dominance of agrostological groups of the genus *Andropogon* and *Hyparrhenia* [12]. The permanence of these grasses is ensured by bushfires.

Marked by rainfalls with average precipitations which vary from north to south, the climate is of the Sudanian and Sudano-Sahelian type. In the northern sector, the average annual rainfall is around 800 mm/year while in the southern sector, up to 1200 mm/year is recorded [15]. Climatic variations with drying tendencies are increasingly observed.

The region is crossed by a dense hydrographic network whose main collector is the Benue. Soils there are varied. There are ferruginous soils, fersiallitic soils, raw mineral soils; poorly evolved soils; hydromorphic soils; and leached tropical soils [16].

On the administrative level, the study area touches all the departments of the Region, large areas of which are devoted to protected areas, in particular three national parks (Benue, Bouba N'djidda and Faro) and 28 Areas of Hunting Interest. In 2002, the population of this area was estimated at 1.600 000 inhabitants, with a density of 18 per square kilometers [17]. In 2014, this population increased to 2.378 489 inhabitants, for a density of 35.94 inhabitants per square kilometers [17]. The strong demographic growth in the whole area increases the pressure on natural resources by hastening the process of degradation (desertification). The area belonging to a fragile ecosystem.

2.2 Choosing of Sentinel-2 Data from the MSI Instrument

This remote sensing work aims to map bushfires through sentinel-2 optical data. They come from the MSI (Multi Spectral Instrument), a recent satellite launched on June 23, 2015, by the High-Resolution Optical Space Mission of the European Space Agency (ESA). The observation period goes from the last ten days of October (beginning of the dry season) until the end of April (end of the season). The series of sentinel-2 images offer advantages in that, they are characterized by a high spectral resolution (10 m), a high spatial swath (about 290 km), a good temporal frequency (10 days) and a high richness spectral (13 bands). Six bands were necessary for this work, namely B2 (λ=492.4 nm); B3 (λ=559.8nm); B4 (λ=664.5nm); B8 (λ=832.8nm); B11 (λ=1613.7 nm) and B12 (λ=2202.4 nm).

2.3 The Material Used

From the field to the laboratory, the equipment used consists of a GPS for the geolocation of burned areas, monitoring and characterization sheets for stations and vegetation, and a camera for taking pictures. The images acquired free of charge from http://eros.usgs.gov/sentinel-2 are processed under QGIS 2.18, where the maps were produced while the statistical processing and graphics were carried out in Excel

2.4 Data Processing

2.4.1 Identification and mapping of burnt areas

Depending on the level of scale taken into account, two types of measurements of the passage of fires are developed in this work: the intraannual measurement which includes both the burned area and the period of occurrence of the fires, and the inter-annual measurement which refers to the frequency of fire and the dominant period of fire occurrence. The calculation of all these parameters is based on the ability to identify the burnt surfaces and to determine for these surfaces the period of occurrence of the fire in the year. Thus, two methods are known in the literature for the identification of burnt surfaces [11]: The first, called the unitemporal method, consists of analyzing a single post-fires image on which the spectral signatures of the burnt surfaces are compared and not burnt. The second method, called multitemporal, is based on the analysis of at least two images acquired before and after the fires. In this case, it is and analyzing of the variation over time of the spectral signature of the burnt surfaces for the same zone on different dates during a year. Hence the classification of fires according to periods (early fire, intermediate fire and late fire) on the same map corresponding to an indicated season. Both methods were considered

The fires were highlighted by the colored composition of the 12-11-2 bands which opposes B12 to B2, that is to say the band of short wave infrared (SWIR) to the band of blue. The latter is sensitive to the smoke above the fires, while B12 testifies to the heat of the flames. However, burnt surfaces can also be detected by measuring the difference between B8, i.e. the near infrared (NIR) band, sensitive to the chlorophyll activity of plants, and B11 (in the SWIR).

2.4.2 Choosing of spectral indices for the detection of burnt surfaces

In the literature, there are several spectral indices which make it possible to detect active fires or burnt surfaces. This work consists in testing the power of separability of burned and unburned surfaces of 03 indices, namely the Normalized Difference Vegetation Index (NDVI) which exploits the spectral bands of red and near infrared, the Normalized Burn Ratio (NBR) which exploits the near infrared and middle infrared bands, and the Soil Adjusted Vegetation Index (SAVI) which is also generated from the red and near infrared bands (Table 1).

The choice of these indices is justified by their respective particularity in distinguishing burnt or unburnt surfaces according to the periods of occurrence of the fires (early fire, intermediate fire, late fire). Indeed, the Sudanian savannahs are particularly burnt each year and throughout the dry season. The more the dry season advances, the more the grasses are senescent. There are also many degraded savannahs within the Sudanian savannahs. In addition, the dry season tends to be prolonged with the late arrival of the rains and their early departure. The NDVI and the SAVI are necessary insofar as these indices make it possible to characterize the early fires, by individualizing the still active vegetation. However, NDVI has limitations. At the heart of the dry season, the grasses are senescent and lose their photosynthetic activities almost completely (except in the lowlands). In this case, the influence of bare soils becomes quite obvious. Therefore, it is difficult to separate the spectral responses of a burnt surface, bare soil, senescent grass cover or a field harvested during the dry season in this case. Hence the importance of retaining the NBR adapted to the characterization of this type of surface during the dry season and in degraded savannahs, making it possible to overcome the limits of the NDVI.

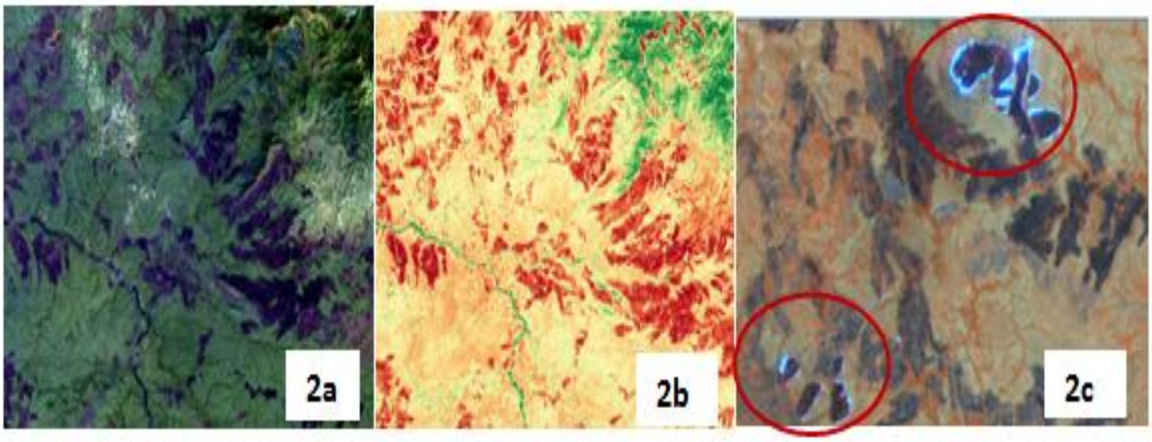


Fig. 2. Composition 12-11-2 (2a), NBR burned area index (2b) and flame detection (2c)

Table I. Spectral indices tested for the identification of burnt surfaces

Spectral indices	Formulation	References
Normalized Difference Vegetation Index (NDVI)	$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}}$	Rouse J. W. et al. [18]
Normalized Burn Index (NBR)	$\mathrm{NBR} = \frac{\mathrm{NIR} - \mathrm{SWIR}}{\mathrm{NIR} + \mathrm{SWIR}}$	Key & Benson [19]
Soil Ajusted Vegetation Index (SAVI)	$\mathrm{SAVI} = \frac{(1 + \mathrm{L})(\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R} + \mathrm{L}}$	Huete A. R. [20]

NIR: Reflectance in the near infrared (B8)
R: Reflectance in the red band (B4)
SWIR: Reflectance in the short wave infrared (B12)
L: Constant (fixed at 1)

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 The distribution of burnt areas and its determinants

The distribution of fires (fig. 3) depends on many factors. Maps of the distribution of fires from 2015 to 2020 show that fires in the Sudanian savannahs are observed more in the southern sector than in the northern sector. Indeed, the northern sector is characterized by an abundance of degraded savannahs with a tendency to steppes, clumps of discontinuous grasses dotted with shrubs. The southern sector is dominated by wooded savannahs, wooded savannahs and shrubby savannahs with a continuous grass cover, the main fuel for bush fires. The spatio-temporal extension of the fires therefore follows this North-South gradient, that’s to say the phytogeographical configuration of the plant cover, thus determining the plant material or combustible biomass available. This observation is linked to the North-South climatic gradient according to which the North sector receives an average of 800 mm/year of precipitation while the South sector receives an average of 1200 mm/year. This factor is first of all predetermining the plant cover, especially the grass cover (particularly seasonal) and then the passage of fires which follows the state of the biomass.

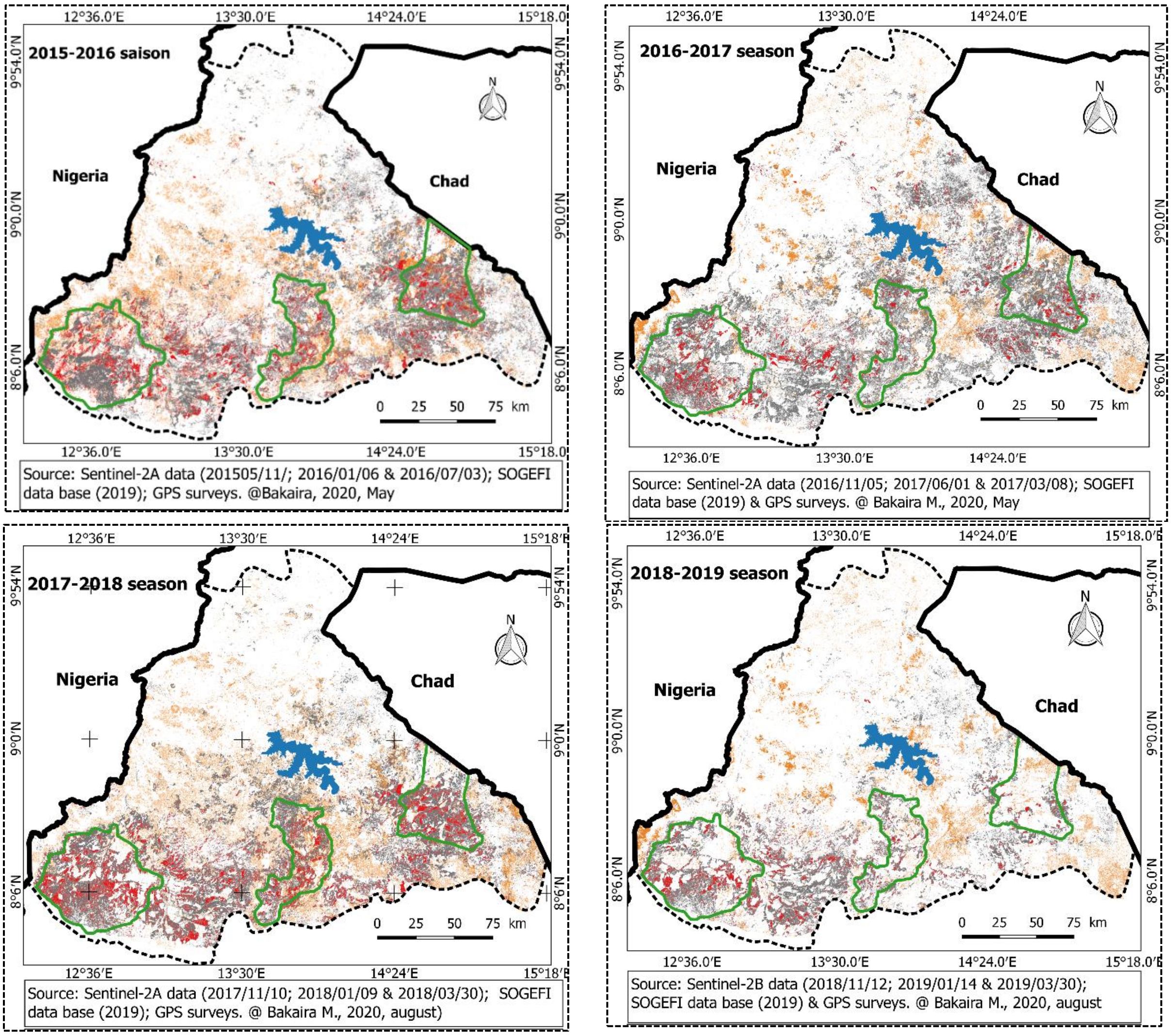
In addition, beyond the North-South climatic gradient, the variation in annual burned areas would also be linked to rainfall variations. Dry years (or early onset of the rains) are associated with an abundance of early fires, while wet years (or late onset of the rains) experience less of this type of fire. It is the case for the 2015-2016 seasons; 2016-2017 and 2017-2018. Clearly, the drying out or humidity over the course of a year determines the level of exposure of savannahs to fires in that the grass cover, which dries up as soon as the rains start, is immediately set on fire.

From the point of view of the organization of landscapes or social practices, the distribution of fires depends on anthropogenic pressure and production systems which explain the state of the vegetation cover by the activities likely to cause fires. The extension of the burnt surfaces is therefore a function of the vocation of the space. From this observation, early fires and intermediate fires are extended more in parks than in another area, namely residential and agricultural areas.

Indeed, the parks are the object of covetousness by the breeders who stay there voluntarily and clandestinely with their cattles. This would therefore explain the frequency of fires (although prohibited from use) counting for the regeneration of rangelands. However, the parks are subject to a mechanism for the protection of resources and effective control of activities. But, the apparent paradox of the extension of fires in these protected areas compared to ordinary areas is explained first by the availability of combustible plant material and also by the fact that the residents of these protected areas perceive them as reservoirs of resources. Because, compared to the multiple use areas, the parks are quite preserved, containing (in places) a well stocked vegetation whose continuity of the grass layer (main fodder resource) facilitates the passage of fire. As a result, late fires are much more common in ordinary areas including fields and residential areas. In this case, these are agricultural clearing fires that occur at the end of the dry season for the establishment of new plots or for the cleaning of existing ones.

The spots burned by this type of fire are therefore characterized by their discontinuity, reflecting a small quantity of consumable biomass or the fragmentation of the landscape by human developments, namely crops. Conversely, residential and cultivation areas do not experience as many early or intermediate fires because the latter are harmful to plantations that have not yet been harvested at the start of the season. Consequently, the scorching spots collected in the agroforestry mosaics during this period (early fires) refer to preventive agricultural fires. It's about fires that are set around fields that have not yet been harvested to anticipate the occurrence of a hazardous and catastrophic fires.

Moreover, apart from Mbororo livestock which need so much of area, small production units exist in the land, bringing livestock and agriculture together. It should also be noted that the grass layer of agroforestry mosaics is largely made up of annual species, which do not regenerate after the passage of fires. Agro-pastoralists familiar with this process avoid and limit early fires and intermediate fires in agroforestry mosaics, even after harvest, to avoid destroying all the residues of the fields used as pasture for their animals. This also explains the low rate of early fires and intermediate fires in multiple use areas. Farmers sometimes have knowledge and know how to manage bushfires in their respective territories.



Source: Sentinel-2A data (201505/11/; 2016/01/06 & 2016/07/03); SOGEFI data base (2019); GPS surveys. @Bakaira, 2020, May

Source: Sentinel-2A data (2016/11/05; 2017/06/01 & 2017/03/08); SOGEFI data base (2019) & GPS surveys. @ Bakaira M., 2020, May

Source: Sentinel-2A data (2017/11/10; 2018/01/09 & 2018/03/30); SOGEFI data base (2019); GPS surveys. @ Bakaira M., 2020, august)

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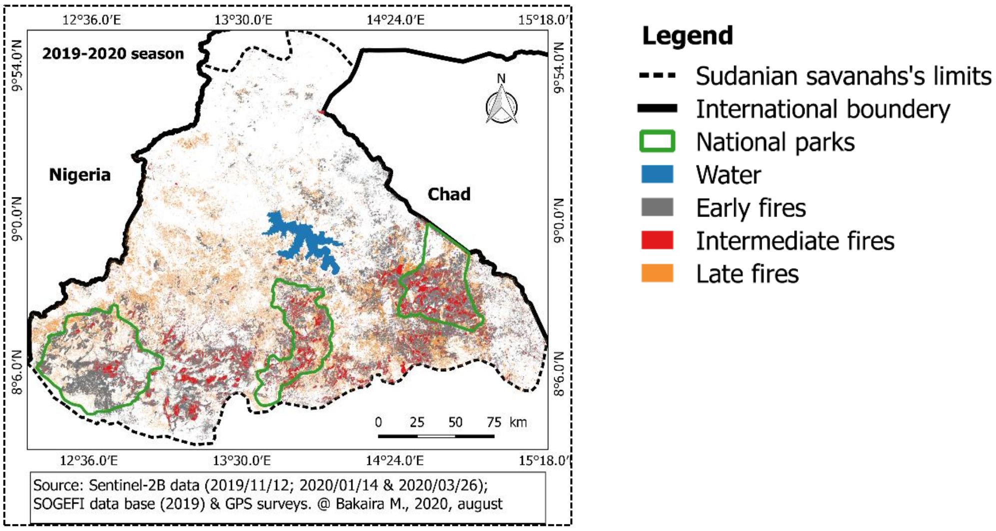


Source: Sentinel-2B data (2019/11/12; 2020/01/14 & 2020/03/26);
SOGEFI data base (2019) & GPS surveys. @ Bakaira M., 2020, august

Fig. 3. Distribution of annual burnt areas by type of fires from 2015 to 2020

3.1.2 Quantification of burnt areas and interannual variation in the number of early and late fires over the period from 2015 to 2020

3.1.2.1 Quantification of burnt surfaces

There is a disparity between the burned areas in hectares (ha) from one season to another (fig. 4). This disparity testifies the random and dynamic character of the fires. Compared to fire types, the amount of area burned by early fires for the entire series is much larger than that burned by other fire types. It reached 400.000 ha in 2016; 375.000 ha in 2015 and 2017 and 300.000 ha in 2019. Intermediate fires are in the background in 2017 and 2019 (275.000 ha) and in 2015 (250.000). In 2016 and 2018, this type of fire marked the lowest quantity of burnt areas, namely 85.000 ha and 100.000 ha respectively. As for the late fires, the quantities of burnt surfaces vary from 175.000 to 320.000 ha for the series. These values place late fires in the background compared to other types of fires in 2015, 2016 and 2018.

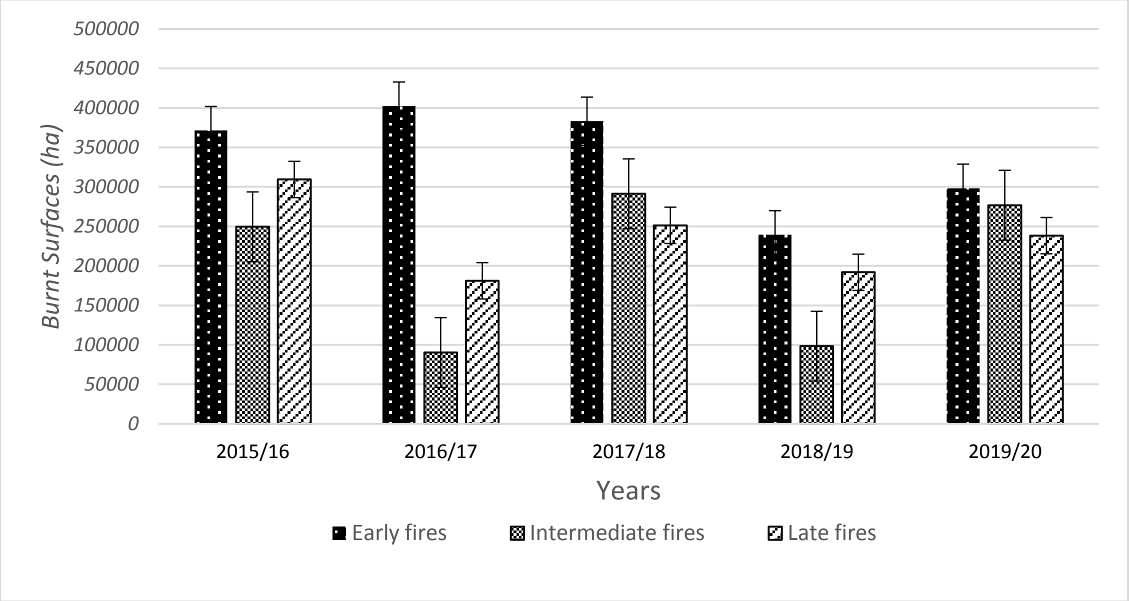


Fig. 4. Quantification of burnt areas from 2015 to 2020 by type of fires

Over the entire series of observations, the analysis of the frequency of fires shows that the savannahs are mainly traversed by early fires (October and November) then relatively by intermediate fires (December to January) and late fires (February and March). However, considering this disparity, the monitoring of the profile of all the burnt surfaces for the entire series is essential.

The temporal evolution profile of the quantities of burnt surfaces (Fig. 5a) makes it possible to question the gradual increase or reduction of burnt surfaces over time and by types of fires.

The result of this monitoring is a sinusoidal curve which shows that the fires vary randomly every year. This variation largely depends on the parameters mentioned above, namely the climatic conditions and the social practices. In 5 years of observation, the quantities of global burnt surfaces vary simultaneously upwards and downwards. Consequently, it is not possible to establish a relationship of progressive or regressive evolution in terms of the quantity of areas burned over time. It is therefore fair to consider bushfires as a normal and random activity whose propagation factors are relatively constant and variable from one year to another. Doesn't this variation also mean that the fire propagation factors are repeated? Observation of the profile of the proportions of burns by types of fires (Fig. 5b) further confirms this hypothesis.

Moreover, the profile of the variation in the percentage of annual burnt surfaces by types of fires (Fig. 5b) illustrates two facts: firstly, the proportion of seasonally burnt surfaces and secondly, the evolution of this proportion by types of fires on the 05 years studied. The percentage of burnt surfaces by types of fires shows that early fires are much more important than intermediate fires and early fires. Their proportion is between 35 and 60% of the global burnt surfaces. We then note the proportion of late fires which is between 25 and 35 % of the global burnt surfaces, while the intermediate fires represent the smallest proportion of the series whose values are between 15% and 35% over the period considered. In the assessment of savannah fires over this period, we then observed more early fires than late fires and more late fires than intermediate fires. Taking into account the various factors that influence the fire regime, this quantification of the burnt areas makes it possible to develop a diagnosis of the state of the fuel, which is mainly the herbaceous layer. However, it is also necessary to assess the place of each type of fire in all the annual burnt areas.

3.1.2.2 Interannual variation in the number of early and late fires compared to the average area burnt

The analysis of the variation of the fires through the deviations of the burnt surfaces compared to the average for the series considered makes us to notice that, each season has a specific character according to the types of fires.

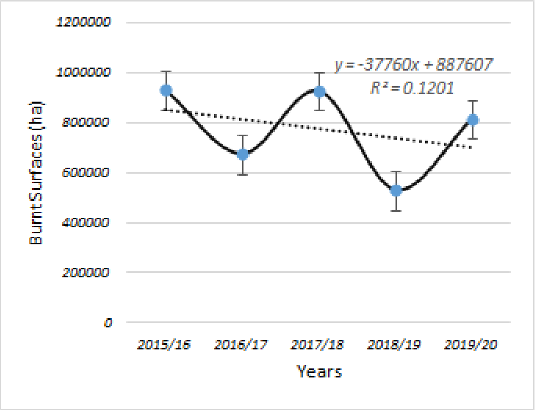


Fig. 5a. Burnt surfaces from 2015 à 2020

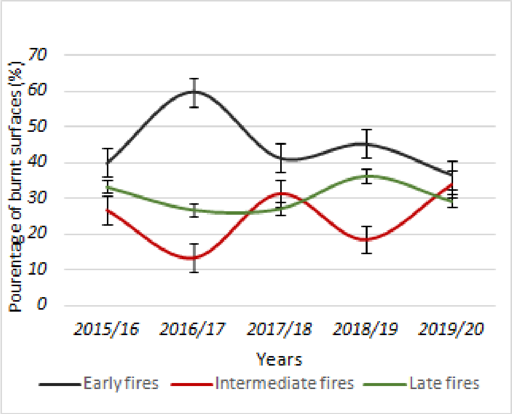


Fig. 5b. Pourcentage of burnt surfaces

Fig. 5. Profile of change in burned areas and percentage of burned areas in 2015 and 2020

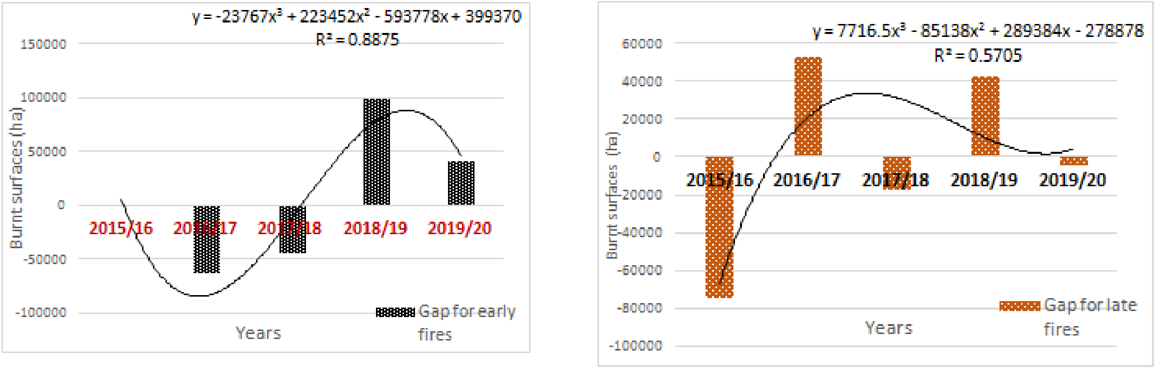
For early fires (figure 6a), the first three seasons of the series have gaps of negative signs. This shows that the quantity of surfaces burnt by this type of fire is higher than the average for these seasons. The most significant season in this case is that of 2016/2017 with a difference of -65.000 ha. Whereas, for the last two seasons, these differences are positive signs, meaning that the quantity of areas burnt by early fires is lower than the average of all areas burnt for the series. The dominant season in this case is that of 2018/2019 with a difference of 100.000 ha.

For late fires (fig. 6b), two seasons carry positive signs deviations, namely the 2016/2017 and 2018/2019 seasons, the other three seasons carry negative signs deviations. These findings show that, in the first category, the areas burnt in the late fires are lower than the average while in the second category, they are higher than the aforementioned average of the series. The 2015/2016 season, whose gap has a value of -75.000 ha, is much more highlighted in this regard.

These differences in both upward and downward variations in the differences in areas burnt per year and per types of fires show that fires are constant phenomenon over the years and that we would not establish an increase ratio for this purpose or gradual regression of any type of fire or burnt surfaces over 05 years of observation. Whereas, we better understand the dynamics of bushfires through a synchronic approach to the analysis of socio-environmental parameters that should be well analyzed.

3.1.3 Comparison of the values of the separability indices and detection of burnt surfaces

The application of three spectral indices for the mapping of burnt surfaces allowed us to study the discriminating power of each spectral index according to the periods of occurrence of the fires and the method used. Healthy vegetation shows very high reflectance in the NIR and low reflectance in the SWIR portion of the spectrum. This is then the opposite of what is observed in areas devastated by fire. Recently burnt areas, exhibit low reflectance in NIR and high reflectance in SWIR, i.e. the difference between the spectral responses of healthy vegetation and burned areas peaks in both NIR and SWIR regions of the spectrum.

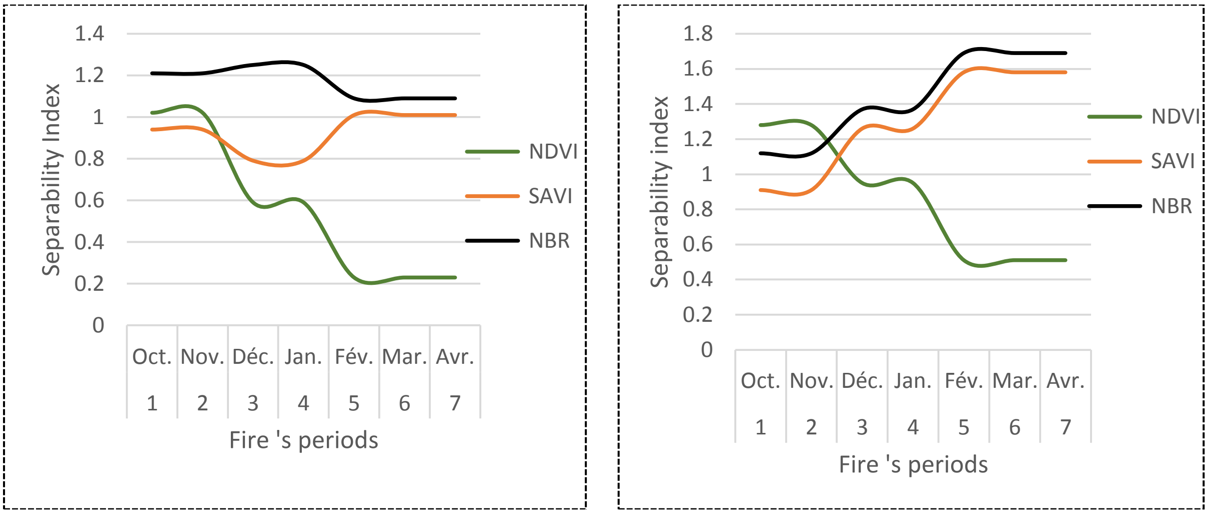


6a. Gaps for early fires **6b. Gaps for late fires**

Fig. 6. Interannual variation in the deviations of burnt areas as compared to the average from 2015 to 2020

Table II. Comparison of separability indices and detection of burnt surfaces

Uni-temporal method				Multi-temporal method		
Separability index	**Early fires**	**Intermediate fires**	**Late fires**	**Early fires**	**Intermediate fires**	**Late fires**
NDVI	1.02	0.59	0.23	1.28	0.95	0.51
SAVI	0.94	0.79	0.93	0.91	1.26	1.58
NBR	1.21	1.25	1.09	1.12	1.37	1.69



7a. Uni-temporal method

7b. Multi-temporal method

Fig. 7. Profile of separability indices according to the two methods and according to the periods of occurrence of fires

Thus, the NDVI makes it possible to separate burnt and unburnt surfaces only in the context of early fires, whatever the method used. For intermediate fires and late fires, its power of separability weakens as the dry season progresses (Table II). The values of the indices, less than 1 for these periods of occurrence show that it does not make it possible to effectively separate the burnt and unburnt surfaces at the heart of the dry season because, they are linked to the chlorophyll activity of the plants.

The SAVI gives better detection of intermediate fires and late fires according to the multitemporal method. Whereas, in the unitemporal method, it remains insignificant and constant for all periods of fire occurrence. Although its values are sometimes close to 1, it does not allow efficient separation of burnt and unburnt surfaces from a single post-fire image.

The NBR, makes it possible to detect burnt areas throughout the year, regardless of the period of occurrence of the fires and using the two methods (Figs. 7a and 7b). In the multitemporal method, its power of separability is a little more marked because the values of the indices increase with the advance of the dry season. It is therefore suitable for monitoring fires in disturbed and degraded savannahs.

3.1.4 Fire actors and their objectives

It does'nt seem obvious to identify the actors of the fires given the repressive position of the State in relation to their lighting and also the interweaving of agro-pastoral activities. The common and ordinary attitude of burners is hiding. Indeed, the law n° 94/01 of January 20, 1994 relating to forests, fauna and fishing prescribes in its article 14, paragraph 1, the formal prohibition of the provocation of fires in the national forest domain. It punishes for this purpose the act of lighting fires in its article 156. These provisions passed on by the managers (and not specifying the particular case of the savannahs), oblige the populations to renounce their practices, even if they seem socially founded and justified. The prohibitions having a formal character, peoples behave like stowaways in the use of bushfires for fear of repression. Consequently, monitoring fires through the actors becomes complex. So, it's therefore made by a deductive method based on the vocation of burnt areas and the period of occurrence of the fire which expose and which explain the motivations or the specific interests to each category of burners (table III). This approach contributes to the understanding of the functional aspects of the savannahs which are of a notorious ecological particularity. It is indeed a competitive use of resources and spaces that makes fire management difficult.

Table III. Temporal classification of fires and their observed potential impacts

Fires	Occurrence's Periods	Ecological impacts	Spatial extension
Early fires	October & November	Partial destruction of regrown semi-senescent perennial grasses; strong increase in low woody species	Closed formations and intermediate formations with continuous perennial grasses in parks and in poorly cleared bushes
Intermediate fires	December & January	Almost total destruction of senescent and regrowth perennial grasses ; relative increase in tall trees	Open formations, closed and intermediate formations with perennial and annual grasses in parks and in relatively cleared bush, cultivation and residential areas; outskirts of the parks
Late fires	February ; March & April	Total destruction of senescent perennial and annual grasses and low woody plants favoring the tree-grass balance ; no regrowth ; tree limitation	Degraded open formations, hydromorphic sectors ; Cultivation and residential areas, outskirts and interiors of parks

3. 2 Discussion

3.2.1 Remote sensing and fire mapping

The need for monitoring by remote sensing of large-scale fires is essential. This was reported by [2] through a multi-scale study in West Africa. Remote sensing data in general and Sentinel-2 image scenes in particular, through their spectral richness and high resolution contribute to the monitoring of burnt areas in savannahs. Burnt surfaces and active fires are detectable first through the raw images, then through the colored composition and also through the elaboration of spectral indices. Each spectral index has its own ability to separate burnt and unburnt surfaces. The joint application of the unitemporal and multitemporal methods therefore makes it possible to choose the spectral indices capable of separating the burnt and unburnt surfaces according to the periods of occurrence of the fires and the state of the land occupation. This method, which has the merit of being generalized, has also been tested by [11] and [21].

However, spatial analysis has limitations in evaluating such a dynamic and random phenomenon as fire. Indeed, this work has shown that fire monitoring requires taking into account the various environmental and social variables that surround it. Assessing the variation in burnt surfaces on the basis of dated satellite image scenes alone is not always sufficient, because the importance of burnt surfaces depends on several factors, in particular the climatic gradient, the intensity of the wind during each season and the abundance of the biomass which is the grass cover in place. These results are similar to those of [22]; [23]; [24] and [8] who estimate that fire variations are linked to variations in socio-environmental conditions. However, rainfall and ecological data are variable and dynamic from one year to another. This then explains the variation in burnt areas from one campaign to another. In practice, if we consider that the same surfaces are set on fire every year and at the same period, the burnt surfaces importance will not always be the same because of the variation in environmental conditions and social practices. This makes the comparison of the profile of the annual burnt areas obtained by processing series of images questionable, and therefore of the spatial analysis of a dynamic phenomenon [25].

3.2.2 On the apparent paradox of the extension of fires in parks

Early and intermediate fires are observed more in parks than in unprotected areas. We have explained this on one hand by the state of the grass cover and on the other hand by the pastoral desire of the breeders of the parks. Indeed, the parks still contain biomass that can be burnt and therefore, most of the fires that pass through them have the character of pastoral fires. Similar observations have been made by [2], [21], Valéa and [22] who demonstrate that protected areas are regularly burnt in relation to their peripheries because of the vegetation cover abundant that they close, and also because of the development strategies put in place by the managers. So in the context of a protected area, apart from the (very limited) development fires, the breeders are bold to invade the protected areas, despite the measures taken to limit all access. Also, [26] had meant it. Considering this type of socio-environmental dynamics, mapping by remote sensing proves to be an essential tool for the diagnosis of the state of the vegetation cover and for the management of protected areas, as demonstrated [27].

3.2.3 Fire: Environmental constraint or management tool for protected areas ?

In the parks of North Cameroon and their outskirts, the issues related to bush fires are linked to the period of the fire and the vocation of the space burnt as a result, because the Sudanese savannahs include fire from the functional point. These observations were also made by [28] and [29] who showed at the forest-savannah interface that 93% of the burnt areas concern savannahs. Without denying the harmful effects of fires, there would therefore exist in the Sudanese savannahs “catastrophic fires” and “useful fires” depending on the actors, the period and the environment considered. Protected area managers and administrative authorities believe that most fires in parks are caused by “unknowns”. Our cartographic findings show that it is much more about early fires and intermediate fires, attributed to pastoral activity.
However, some fires start in the outskirts and gradually follow the continuity of the grass cover to the parks. Still others have as their starting point tracks inside the park, testifying more or less to a diversified anthropic origin. Although favoring the regrowth of perennial grasses and

the opening of movement areas for wildlife, hazardous fires represent a constraint for the parks through their disruptive effects on wildlife and micro-organisms in the savannahs. These results corroborate those of [7] for whom fires in protected areas come under ecological disturbance.

This nuanced look then makes it possible to overcome the forest arguments which do not establish the particularity of the Sudanese savannahs, as well as the legal paradox of law n ° 94/01 of January 20, 1994 on the regime of forests, fauna and fishing, which drowns out the particularity of the savannahs in the forests. In other words, this institutional logic does'nt seem to favor the daily people's life and the functional aspects of the Sudanese savannahs insofar as fire is considered much more as an environmental risk than a management tool. Fire management should therefore be better studied and nuanced through remote sensing methods and the analysis of the statements of actors, to make it a structured and planned environmental management tool. Conversely, if fire were to be isolated considered an absolute threat, the parks would be under extreme disturbance.

4. RECOMMENDATIONS

The results of this work revealed that bush fires are random variables that depend on both the vocation of the environment, the types of land use and social practices. For protected areas, we observed that the extension of early season fires concerns parks much more than in mundane areas, meaning that the fires conform to the availability of combustible biomass that the parks contain.

The study therefore recommends geomatics for the diagnosis of the state of the vegetation cover in the management of savannahs and protected areas. Mapping by remote sensing is indicated as a preliminary decision-making tool in the context of the management of protected areas (whether it concerns interventionist measures, prevention or even planning). From updated GIS (Geographic Information Systems) databases, we can better understand fire trends in order to anticipate accidental fires in the context of planning and management of protected areas.

5. CONCLUSION

The geographical monitoring of fires makes it possible to understand that they are dynamic and complex phenomena. Considering the different methods of their use in the savannah, it appears that the interweaving of rural activities pertinently justifies the seasonal use of fires, even in the context of a protected area. We cannot therefore witness a situation of fire's absence in the savannahs, because it shall be a functional disturbance of the ecosystem and disruption of human activities.

The spread of fires depends both on environmental determinants and also on social practices in place. In their spatial extension, the fires follow the continuity of the herbaceous cover (combustible biomass). This is how we observe their frequency in parks compared to multiple-use areas (fields, residential areas), sometimes degraded under the effect of pressure from overgrazing and agricultural clearing, with a deficit of biomass to burn. The absence of fire would therefore be an indicator of degradation of the herbaceous cover, while the continuous burning testifies to a fairly abundant grass layer. The mapping and monitoring of fires are becoming priority tools for diagnosing the vegetation cover in the savannah, in particular the state of the grass layer.

As for the issues related to fires, their devastating nature, long decried by the administration and the media, does not always sufficiently justify their ban. In reality, the issue of fires depends on the actors (those who set the fire and who benefit from it or not) and also on the vocation of the environment. Moreover, spatial analysis and observations according to social science approaches do not at first sight reveal a disaster linked to fires, but rather a close link with the social practices in place at the real ranges. Fires therefore have ambivalent effects and their best use would require a better understanding of their socio-environmental determinants and the better application of appropriate monitoring tools and methods, namely cartography by remote sensing.

FUTURE STUDIES

In perspective, it would be necessary to gradually study the methods of using fires in a planning approach, integrating all the societal variables, namely the motivations and needs of the populations to want to set fires in the savannahs. This process will consist of determining and defining the places where the fire should be set, the period of occurrence and the purpose. In addition, to make our recommendations operational, future studies will consist of mapping land use and burnt areas on a variety of scales using high-resolution remote sensing data. This work will result in a bushfires management plan for each protected area. It would also be useful to extend the observations to the Guinean savannahs where the stakes linked to agropastoral activities are quite marked.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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