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CLIMATIC FACTORS AND VEGETATION FIRES IN THE IFFOU, N'ZI AND MORONOU REGIONS, EAST CENTRAL IVORY COAST: CASE OF THE 2015-2016 SEASON

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Abstract

In Ivory Coast, vegetation fire occurs frequently. These phenomena reduce agricultural yield due to the land and green cover degradation. This study focuses on the regions of central-east Ivory Coast, which are highly exposed to this scourge every year. The purpose of this study is to analyse the climatic conditions under which vegetation fires start in the dry season, espacally in 2015-2016 season, and to determine the critical thresholds of climatic factors in order to prevent this disaster. To achieve our goal, statistical analyses of active fire data for the 2015-2016 season (got from the MODIS imaging spectrometer on board the Terra and Aqua satellites), and climate data were carried out. The results show that during the 2015-2016 season the fires recorded are from December to February precisely between the 2nd dekad of December and the 2nd dekad of February with a maximum occurrence reached in the 3rd dekad of January. Spatially, it shows clearly that the vegetation fire phenomenon is localized in terms of fire severity in the Iffou, N'Zi and Moronou regions of the East-Central. These regions have the highest areas burned with 123505.87 ha and 73091.34 ha respectively. These results also show a high dependence of fires on climatic conditions, particularly high temperatures, low atmospheric humidity and lower than normal rainfall. The critical thresholds that contributed to the outbreak of fires in the regions can be summarized as temperatures above 34°C, relative humidity below 58% and rainfall deficits in the order of -100%.

Keywords: *Vegetation fire, climatic factors, MODIS image, East-Central region, Ivory Coast.*

1. Introduction

For since decenneries, issues related to variability and climate change disturbed the scientific community and policy makers because of their immediate and durable consequences on the environment. Thus, in the world, we are already seeing an increase in average atmospheric and ocean temperatures, massive melting of snow and ice, and a rise in mean sea level. The Intergovernmental Panel on Climate Change (IPCC) predicts in its 2007 report that temperatures will increase by between 1.1°C and 6.4°C over the 21st century. As for these projections, there is not a country immune to the effects of climate change and cannot, on its own, cope with controversial political decisions, industrial developments and other issues that are inseparable and have far-reaching consequences on a global scale. As the planet warms, the rainfall pattern changes and extreme events such as floods and droughts with their associated vegetation fires become more frequent (Ait Bennour & Bensidhoum, 2017). So, among these hazards, which are aggravated by climate change, wildfires are one of the most complex phenomena for regions with high vegetation density.

These wildfires devastate several million hectares of land each year and are the most dangerous natural disaster to human, animal and economic life (Bou Kheir et al., 2006). According to FAO (2001), hundreds of millions of hectares burn in fire-adapted ecosystems in dry areas of West Africa, large areas of Africa south of the equator, Central Asia, South America and Australia. Specifically, 1015 million hectares of boreal and temperate forests, 2040 million hectares of tropical rainforests and up to 500 million hectares of tropical and subtropical savannahs, woodlands and open forests are affected by these fires according to WMO (2005) cited by Dje et al. (2017). The latter are distinguished by the particularity of being both natural and anthropogenic phenomenon. Natural, because they grow in interaction with environmental elements (vegetation, relief, climate) and anthropogenic because some are mostly caused, voluntarily or involuntarily, by man (Belkaid, 2016). In Africa as elsewhere in the world, these fires cause several damages with sometimes dramatic and priceless social and economical consequences on the environment. They also contribute to the loss of cover, soil erosion, decreased soil fertility, increased atmospheric concentrations of CO_2 and reduced atmospheric carbon sequestration capacity (Adouabou et al., 2004; Masahiro, 2003). According to (2004), the season in which these fires occur match with the period when climatic factors are most favourable (heat, drought, wind). In Ivory Coast, precisely in the Central-East regions, vegetation fires caused enormous damage during the 2015-2015 season. Thus, the damages are estimated at more than 4000 hectares of lost perennial crops, 10,000 hectares of reforestation gone up in smoke, 10 villages and 200 huts affected, 17 deaths and material damage of more than 204 billion CFA (CNIESDF, 2017). Although human factors remain one of the major causes of vegetation fires, the determination of climatic and/or meteorological conditions contributing to their outbreaks or as an aggravating factor should be conducted to contribute to decision support tools in forest management. The aim of this work is to investigate the climatic factors that mainly promoted or aggravated wildfires during the 2015-2016 season. It is in this perspective that this research, whose theme is ***« Analyses of climatic factors favorable to wildland fire in the regions of Iffou, Moronou and N'zi,: East Central ivory Coast case of the 2015-2016 season »***

The overall objective of this study is to contribute to the improvement of wildland fire management through climate information that will allow, at the operational level, to improve warning processes and the positioning in the field of monitoring and intervention committees in the framework of wildland fire prevention.

Specifically, it is the responsibility of:

- Analyze the spatio-temporal dynamics of vegetation fires and burned surfaces that prevailed in the 2015-2016 season in the East-Central regions;

- Analyze the climatic conditions under which these fires occurred and also try to explain their evolution according to the meteorological factors of the moment in order to determine the critical threshold of these fires.

2. Presentation of the Study Area

2.1. Geographical Location

Located in the East-Central of Ivory Coast between longitudes 3°40' and 4°55' West and latitudes between 6°20' and 8°10' North, the regions of Iffou, N'Zi and Moronou cover an area of arround 19 560 km². Their respective departmental capitals are Dimbokro, Daoukro and Bongouanou. From an administrative point of view, the regions are limited to the West of Aries and Gbêkê, to the North by the Hambol and Gontougo regions, to the East by the Indenié-Djablin region and to the South by the Agneby-Tiassa and Mé regions. Fig 1 below shows the geographical location of the East-Central regions.

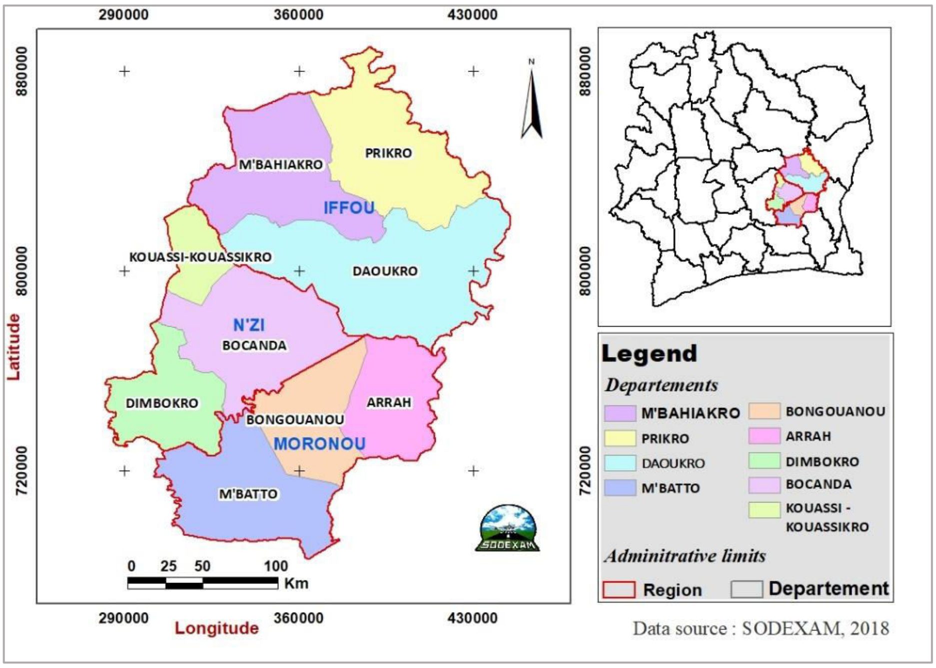

Fig 1: Geographical location of the East-Central regions

2.2. Climate Regimes

The East-Central regions (N'Zi, Moronou and Iffou) have a humid tropical climate with an alternation of four (4) seasons including two (2) rainy seasons and two (2) dry seasons. The seasons of these regions are distributed as follows during the year: (i) a large rainy season from March to June (4 months), (ii) a small dry season from July to August (2 months), (iii) a small rainy season from September to October (2 months) and (iv) a large dry season from November to February (4 months). The annual rainfall average (normal values calculated over the period 1981-2010) in the East-Central regions varies between 1000 mm and 1200 mm. The monthly distribution of cumulative rainfall is highly variable in these regions, April, May, June and October receive nearly 75% of the total annual rainfall. June remains the rainiest month with a maximum of 200 mm on average in the Moronou region (Arrah), about 180.8 mm in the N'Zi region (Dimbokro) and 173.9 mm in the Iffou region (Daoukro). The average monthly relative humidity recorded at Dimbokro station varies lower between 62% and 65% (January-February) and 80% and 82% (July-August) (Normal values calculated over the period 1981-2010). In these regions the relative humidity is generally higher than 70% and varies relatively much during the year. As for the air temperature, the monthly averages of the maximum temperature are reached in February with an average of 36.2°C. The minimum monthly average temperatures are observed in January reaching 21.2°C in the middle of the main dry season when the harmattan is most severe. The average annual temperature recorded at Dimbokro station is around 27°C. Temperatures in these areas are high overall, but vary little over the year.

2.3. Vegetable Formations

In these East-Central regions, the plant landscape reflects humid tropical transition climate, which explains the presence of a diversity of plants. These different lands use units include dense forest, open forest, savannah and cultivated areas (Fig 2). Open forests predominate at about 51.1%, followed by dense forests (24.4%). The savannah is very poorly represented (22%). The weakest plant formations are located in the N'Zi and Iffou regions.

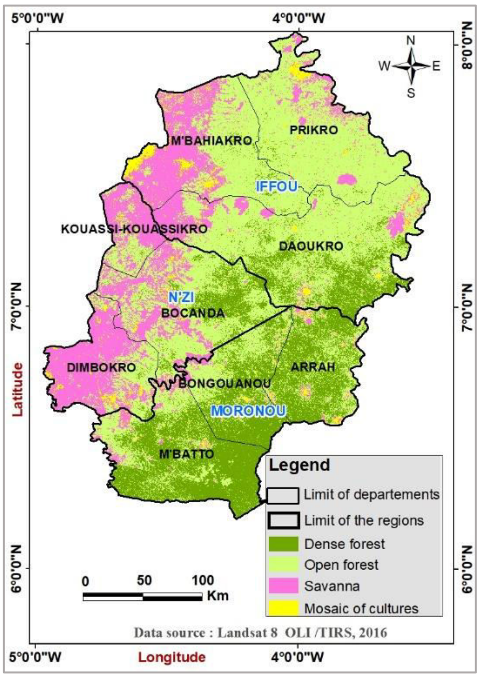

Fig 2: Land use map of the East-Central regions of 2016

3. Materials and Methods

3.1. Data

3.1.1. Climate data

The climate data used in the study come from the database of the Compagny for the Exploitation and Airport Development, Aeronautics and Meteorological (SODEXAM) / National Meteorology Department (NMD) of Ivory Coast. They concern rainfall altitude, maximum temperatures and humidity levels. The data are those of 2016 for parameters other than rainfall amounts for which 2015 was used to assess their distributions. These data were compared to the normal 1981-2010 data. Thus, eight (08) rainfall stations and the Dimbokro synoptic station, located in the study area, were used for the study (Table 1). Due to the lack of data for the wind parameter, only rain, temperature and humidity were used. All these data collected on a daily scale are analysed on a daily and monthly scale.

Table 1: Meteorological measurement network and data periods

Stations	Longitude	Latitude	Period	Station Type
Arrah	-3.97	6.67	2015-2016	Rainfall
Bocanda	-4.52	7.07	2015-2016	Rainfall
Bongouanou	-4.19	6.64	2015-2016	Rainfall
Daoukro	-3.87	7.25	2015-2016	Rainfall
Dimbokro	-4.7	6.65	2015-2016	Synoptic
M'Bahiakro	-4.33	7.47	2015-2016	Rainfall
M'Batto	-4.37	6.47	2015-2016	Rainfall
Prikro	-3.98	7.63	2015-2016	Rainfall

3.1.2. Dry Matter Productivity (DMP) data

To assess dry matter production during the 2015-2016 season in the East-Central regions, dry biomass production data for 2015 were used. They are taken from the database of the AGRHYMET Regional Centre.

3.1.3. Fire data

- Active fires

For this study, Fire Hot Spot data for the 2015-2016 season were used. They come from the MODIS (Moderate Resolution Imaging Spectroradiometer) imaging spectrometer, a sensor on board the Terra orbital satellites, which has been operational since 2000, and Aqua, which has been operational since 2002 and is particularly well suited to the detection of active fires (Giglio et al., 2003). This sensor is equipped with a thermal detection system that measures temperatures on the earth's surface. The Terra satellite passes over the equator every day around 10:30 am and 10:30 pm, while Aqua passes around 1:30 pm and 1:30 am UT. These two satellites provide data on active fires twice a day.

To analyze the dynamics of bushfire density two types of products from MODIS data were used: MOD14A1 (Terra) and MYD14A1 (Aqua), collection 6, made available by the Fire Information For Resource Management System (FIRMS) and accessible from the NASA website in shapefile format: *(http://firms.modaps.eosdis.nasa.gov)* . The satellite algorithm exploits the high emission of infrared radiation from fires by examining each pixel with a spatial resolution of about 1 km (Giglio, 2013).

- Burned surfaces

To quantify the dynamics of the burned area, data from the MCD64A1 product in Collection 6 for the 2015-2016 season were used. The product MCD64A1 is obtained by combining the ground surface reflectance data of MODIS Terra and Aqua. It provides monthly detection of burnt surfaces with a ground resolution of 500 meters (Giglio, 2013), already pre-processed by NASA and available in shapefile, tif.GZ format from the website *(ftp://ba1.geog.umd.edu/)* . These data are available at the regional level. Our study area is located in window 9 which covers most of West Africa.

3.2 Methodology

3.2.1. Tools

For the pre-processing and data processing, we used:

- ArcGIS 10.4 software to extract active lights and calculation of burned surfaces for MODIS images,
- and an integrated environment software (R studio 3.4.4) for statistical analysis of the data and generation of the various graphs illustrated.

3.2.2. Analysis of fire dynamics in the regions

Maps illustrating the spatial and temporal dynamics of MOD14A1 and MYD14A1 active fires and MCD64A1 burned surfaces were produced in ArcGIS 10.4 software in the GCS_WGS_1984 system. Once extracted, these active fire points are ranked on a reliability scale from 1 to 100. For our study, points with a value greater than 30 were kept in order to establish a base containing only the proven fire points. Thus, the temporal analysis of fires consisted in counting on a monthly basis the number of fires and the calculation of the burned areas at the departmental and regional levels. The data collected were used to develop fire evolution curves and to determine the periods of maximum or minimum fire increase during the 2015-2016 season. Concerning the spatial distribution of fires in the study area, a count of the total number of pixels affected by the fire was carried out at the level of each region and department. All of them encountered within a radius of 10 km are added together and the total is divided into the area of the circle of surface units. The spatial analysis identified the areas most affected by the fires, which could thus be described as high-risk areas.

3.2.3. Analysis of the determinants of fire spread in the central-eastern regions

3.2.3.1. State of vegetation cover (estimation of herbaceous biomass)

To assess the state of dry biomass, dry matter production (or Dry Matter Productivity) was used (Swinnen et al., 2015). The DMP represents the overall growth rate or increase in the dry biomass of vegetation. The quantity of dry matter was calculated from the accumulation of the decades of rainfall (April to October) for the year 2015. The mathematical expression of dry matter production is defined by the equation:

$$PPA = 0.01 \times \sum_{dekad\ i}^{dekad\ f} DMP\ dekad$$

$PPA\ (kg\ Ms.ha^{-1})$ = *Production of aerial phytomass ;*
0.01 = *conservation value in kg ;*
$dekad\ i$ = *first dekad of april ;*
$dekad\ f$ = *third dekad of october.*

3.2.3.2. Atmospheric conditions of vegetation fires

This section deals with the comparison of meteorological elements affecting the occurrence and propagation of fires. The study makes it possible to determine the critical thresholds that encourage fire outbreaks.

- Frequency analysis

It consisted in constructing frequency tables by value class and presenting the characteristics of the series by indicators and graphs. Thus, the Sturges formula was used. It made it possible to determine the number k of classes. Thus, for a series of n observations, $k = 1 + (3{,}3\ log\ n)$. The extent of the series was calculated, ($E = Xmax - Xmin$) as well as the amplitude of the classes ($a = E\ /\ k$).The analysis will first be done by superimposing thermal and hygrometric chronicles and the occurrence of wildfires.

- Rainfall analysis

For the analysis of rainfall prior to wildland fires, the number of monthly rainy days for the year prior to 2015 and the rainfall deviation from normal on the day of the wildland fire were calculated.
We considered here the cumulative rainfall from November to the day of the fire during 2015-2016 compared to the normal cumulative rainfall on the same day over the period 1981-2010. The relationship for the determination of the deviations is as follows:

$$Deviation\ (D) = \frac{\sum Pm - Pn}{Pn} \times 100$$

Avec: .$\sum Pm$ *: cumulated rainfall ;*

Pn :. normal rainfall 1981-2010.

4. Results and Discussion

4.1 Results

4.1.1. Temporal distribution of active fires during the 2015-2016 season

The temporal analysis of the number of fires made it possible to show two main phases of evolution during the 2015-2016 season. A first one showing a high fire frequency (November-February) and a second period characterized by a low fire frequency (March-June) (Fig 3). Almost all fires detected during the 2015-2016 season started early in the East-Central regions in the second dekad of December and continued until the second dekad of January when more or less significant outbreaks were detected in the Iffou and N'Zi regions. More than 80% of fires were recorded between the third dekad of January and the second dekad of February during the 2015-2016 fire season. Fires were concentrated over 46 days with a maximum occurrence recorded in January with an average of 300 fires in the Iffou and N'Zi regions. The Moronou region recorded an average of 80 fires during the same season.

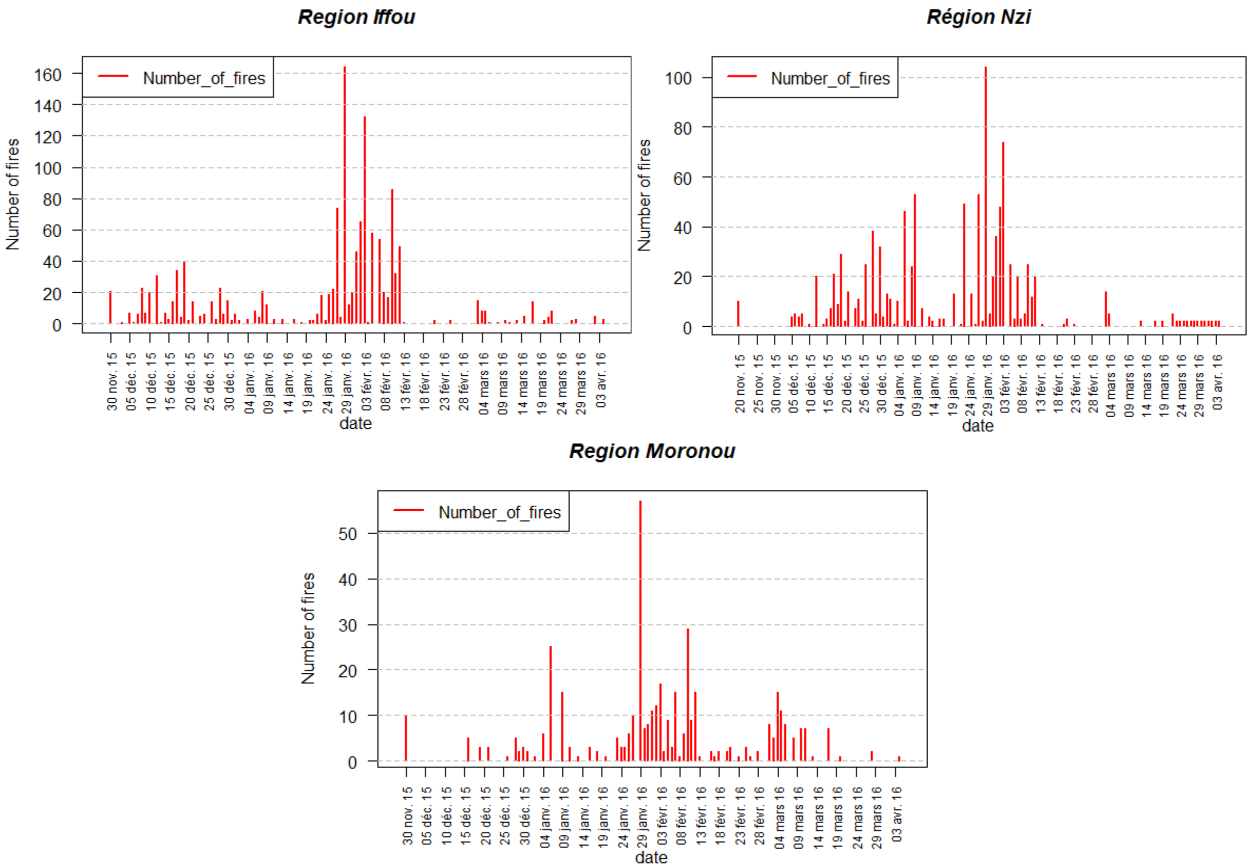

Fig 3: Temporal fire dynamics in the regions of L'Iffou, N'Zi and Moronou (2015-2016 season)

4.1.2. Spatial distribution of active fires and burned areas during the 2015-2016 season

The processing of all images obtained during the 2015-2016 season provided results in the form of maps for each month for which fires were recorded. The compilation of these results resulted in the establishment of maps of active fire points (Fig 4) and burned areas for the months of November, December, January and February (Fig 5)

Monitoring the spatial distribution of active fire points for the 2015-2016 season indicates that fires were present in almost all regions. A total of 2764 fire points were identified in all regions during the 2015-2016 season. Thus, the map of active fire points shows that the burned areas are increasing in the western and northern part of the study area precisely of the Dimbokro - Prikro line. During the 2015-2016 season, 209704.28 ha were burned in the Central-East regions, including 123505.87 ha in the Iffou regions, 73091.34 ha in the N'Zi and 13107.07 ha in the Moronou region, representing 10.72% of the area of the East-Central regions. Also, during this season, January recorded the largest areas burned, including 124095.73 ha (6.34%) and November recorded the smallest area at 5203 ha (0.26%). However, the location of the fire pixels of the burned surfaces during the season shows a difference in distribution between the different departments. This difference in spatial frequency is a function of climate and plant formations in the region. The eastern part (Arrah, Bongouanou) and the southern part (M'Batto) are mainly composed of dense humid forests while the western part (Dimbokro, Bocanda, Kouassikouassikro) and the northern part (M'Bahiakro, Daoukro, Prikro) are mainly composed of dry formations and savannas. Also, when comparing with isohyets, it is in the least rainy western and northern areas that the maximum fire point is recorded. These less rainy areas are prone to vegetation fires.

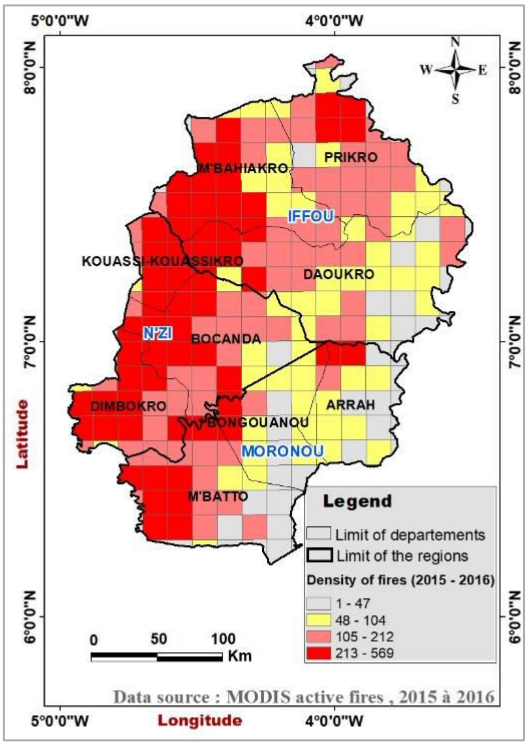

Fig 4: Spatial distribution of active fires for the 2015-2016 season in the East-Central regions

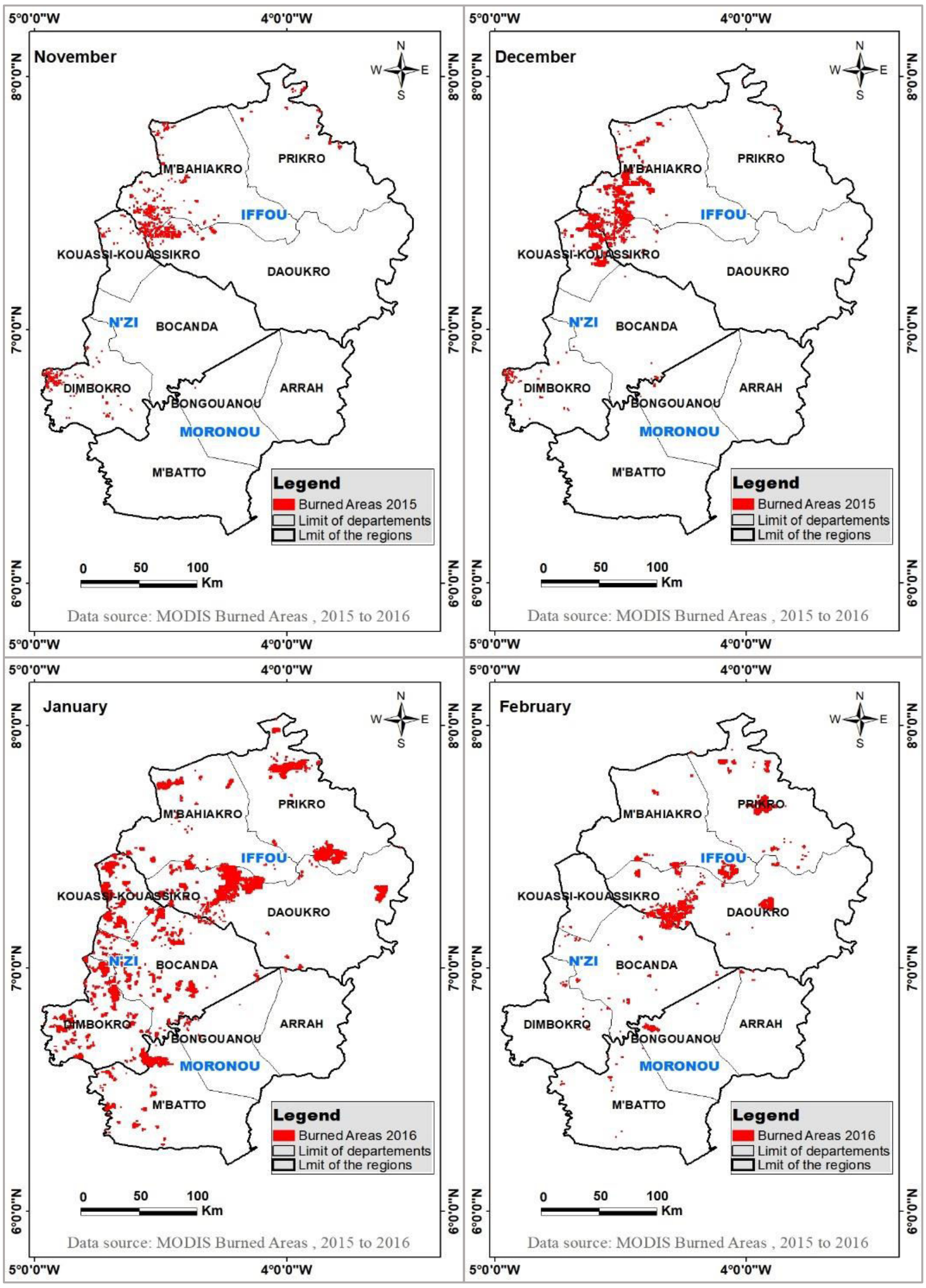

Fig 5: Spatial distribution of burned areas from November 2015 to February 2016 in the East-Central regions

4.1.3. Determinants of fire spread in the East-Central regions

4.1.3.1. Estimation of dry biomass

The amount of dry matter production in the East-Central regions during the 2015-2016 season shows a decreasing production from East to West (Fig 6). The Moronou region has the highest biomass production rate in the regions with more than 4500 Kg/ha of dry matter production. These regions, which are mainly made up of forests, benefit from a favourable climate that allows a water content of plants that makes it difficult for the sun's rays to penetrate. Also, the wet nature of this type of environment slows down the desiccation of vegetation and therefore the spread of fires. As for the Nzi and Iffou regions, production is less than 2500 kg/ha. Comparing with the type of land use, we notice that the herbaceous mat of this savannah zone is mainly composed of grassy formations that have a large bedding of which is easily flammable.

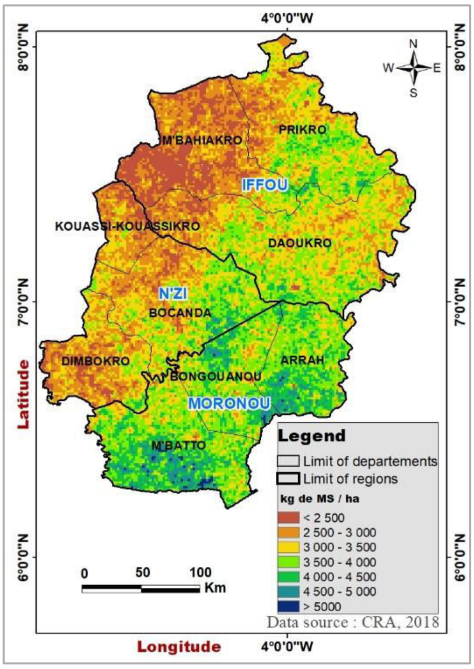

Fig 6: Dry biomass production in the East-Central regions

4.1.3.2. Climatic conditions

- The maximum air temperature

The number of fires as a function of the maximum temperatures recorded at the Dimbokro synoptic station on the day of the fires indicates that during the 2015-2016 season, fires started in the regions from 31°C and reached the maximum threshold between 37°C and 39°C (Fig 7). Analysis of thermal characteristics in the East-Central regions during the fire season indicates that the temperature was high. It is therefore noted that during the 2015-2016 season fires appeared when the temperature was between 27°C and 41°C. Thus, from 29°C there is a rapid increase in the number of fires to reach a peak of 900 fires when the temperature reaches 39°C. These high temperatures have thus affected the state of desiccation of plants and soil. They also affected the evapotranspiration process by increasing the drying rate of plant fuels, which contributed to the outbreak of fires.

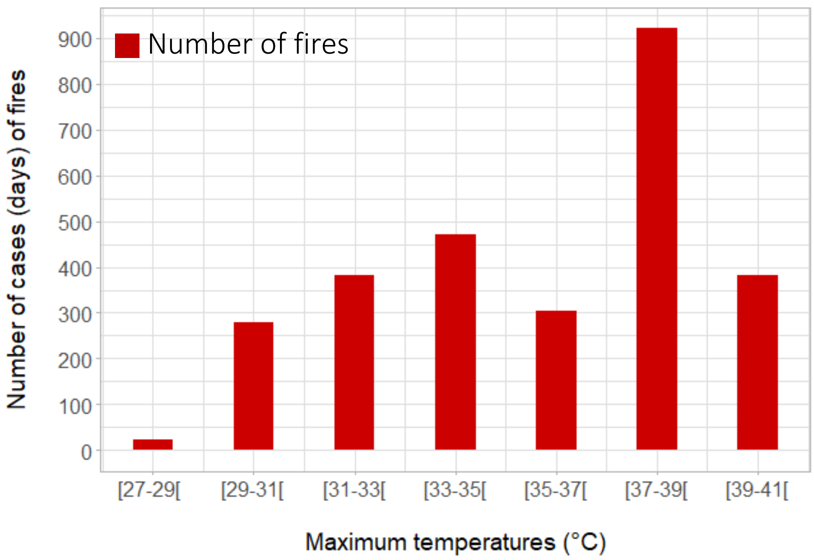

Fig 7: Fire frequency as a function of the maximum temperatures on the day of the vegetation fire

- The relative humidity of the air

Almost all vegetation fires are caused by the ignition of dead leaves and branches. For this waste to ignite, it must have reached a certain degree of very low hygroscopy. Their hygroscopic power being detected, the relative humidity of the surrounding air conditions their water content.

The frequency of fires as a function of relative humidity indicates that more fires were recorded when humidity was low. Fires started with a frequency of 50% where the air humidity was less than 20% (Figure 8). The humidity level generally follows the rainfall profile. It is high during the rainy season and low during the dry season. Thus, the hygrometric characteristics of the East-Central regions during the fire period indicate that 93% and 86% of the fires were recorded when the humidity level was below 40% and 60% respectively. This reflects the behaviour of dry air, which influences the state of desiccation of fuels, favouring the appearance of fires.

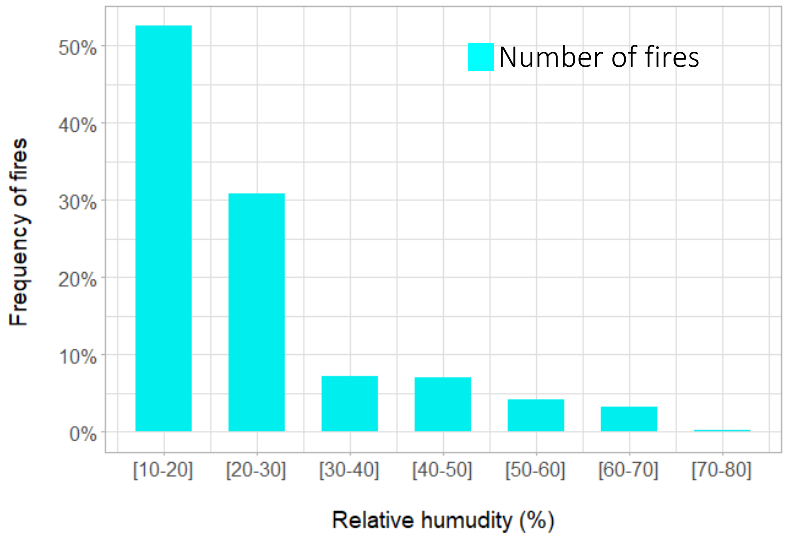

Fig 8: Fire frequency as a function of relative humidity on the day of the vegetation fire

- Rainfall
- **Number of monthly rainy days**

An analysis of the distribution of the number of monthly rainy days at the level of the departments of the regions shows a general trend towards a decrease in the number of days compared to normal (Fig 9 and 10). The number of rainy days was almost lower than normal (less than 10 days) except for the stations of Arrah and Bongouanou. The months of March and April are intermediate months which generally herald the arrival of the main rainy season. It is noted that during these months the number of rainy days is also lower than normal. With the exception of the station of Bongouanou where these months were above normal. As for the months of May, June and July, they correspond to the wettest months in the East-Central regions. Virtually all stations recorded numbers of days that were below normal except for the Bongouanou station where at least 15 rainy days were recorded compared to normal. This record is held by June, the wettest month of the year. September and October are also among the months of moderate rainfall. During these months, the number of days increased compared to the previous months.

This increase is limited to the stations of Arrah, Bongouanou, Dimbokro, M'Bahiakro and Prikro. The number of days reached in these stations is more than 10.

Fig 9: Evolutions of the number of monthly rainy days compared to normal 1981-2010 in Arrah, Bocanda, Bongouanou, and Daoukro stations.

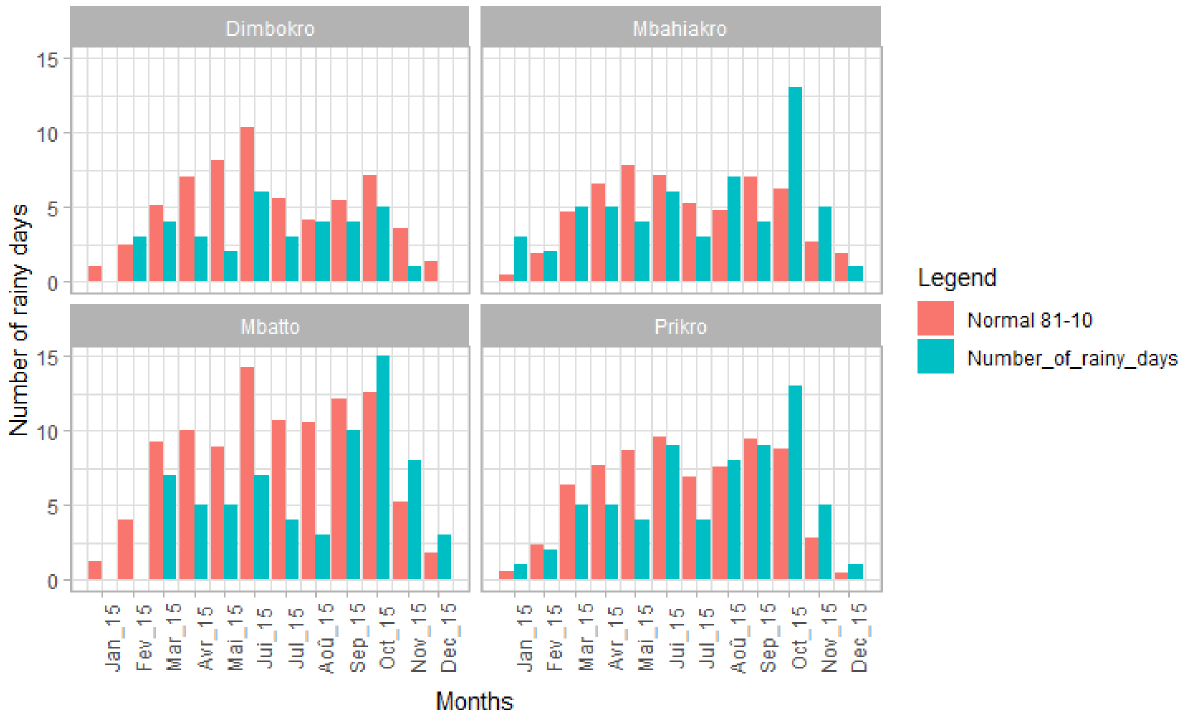

Fig10: Evolution of the number of monthly rainy days compared to normal 1981-2010 in Dimbokro, M'Bahiakro, M'Batto and Prikro stations.

- **Deviation of precipitation from normal on the day of the fire**

The analysis of the number of fire cases as a function of rainfall in the different departments indicates that the number of fire cases was high when the recorded rainfall was low (Fig 11 and 12). Negative values on the x-axis indicate lower than normal quantities. The largest number of fires occur in the range of -15% to -100%. Nevertheless, some so-called early fires were recorded in the departments of Arrah and Bongouanou just after the small rainy season (November). Thus, reduced precipitation has increased vegetation drying and increased fuel desiccation, contributing to increased fire frequency.

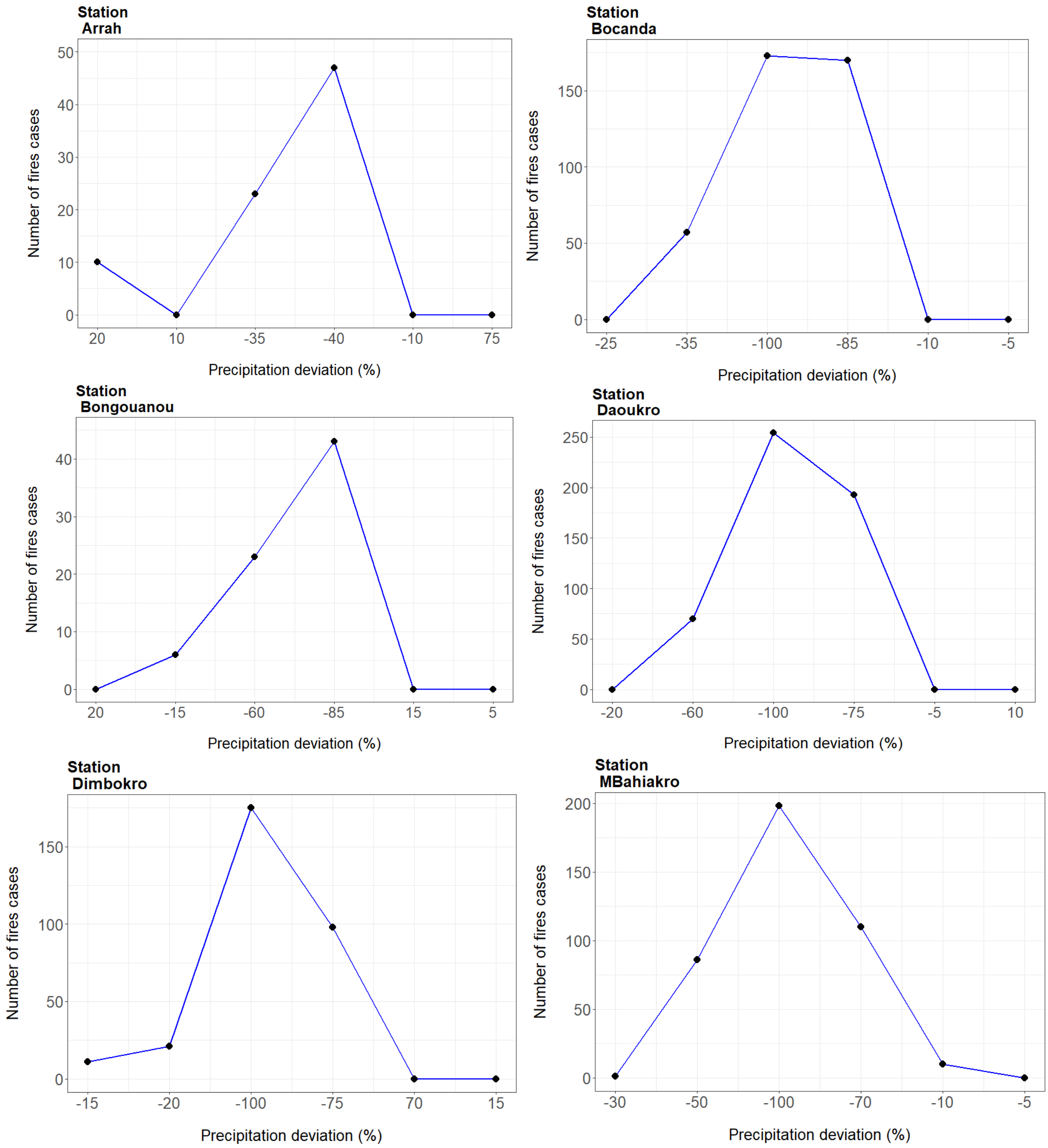

Fig 11: Deviations of rainfall amounts from normal on the day of the fire at Arrah, Bocanda, Bongouanou, Daoukro, Dimbokro and M'Bahiakro stations

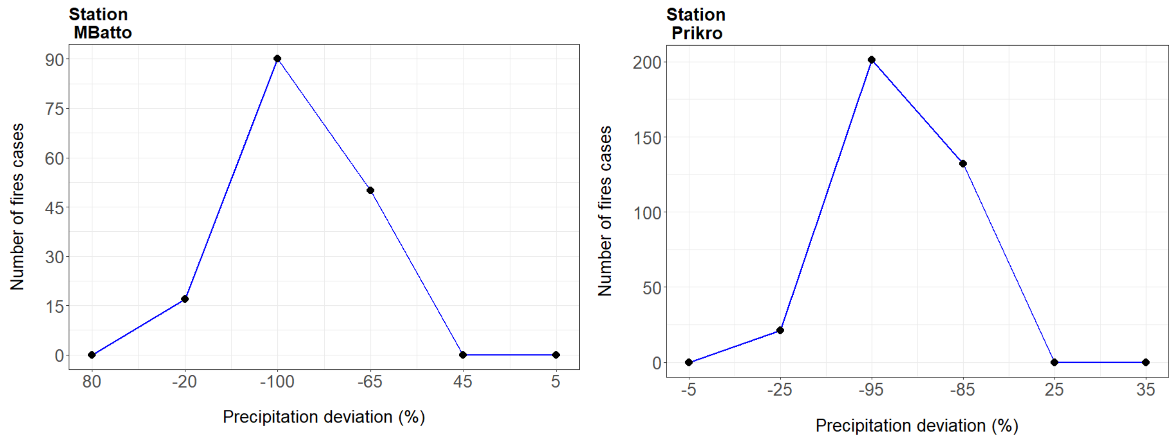

Fig 12: Deviations of rainfall amounts from normal on the day of the fire at M'Batto and Prikro stations

4.2. Discussion

4.2.1. Spatial and temporal distribution of fires and burned areas

The spatio-temporal analysis showed a very high number of fires recorded in the 2015-2016 season for both active fires and burned areas. This can be explained by the global event during this period, which corresponds to the El Niño episodes considered to be one of the most important (WMO, 2017). The results of this study showed that the start of fires during the 2015-2016 season began in November; this corresponds to very early fires that occur after the rainy season (Valéa, 2016). At this time, the vegetation is not dry enough, so it does not allow fires to spread. Thus, the fires detected during the study period reveal a high frequency phase of fires and affected areas in the central-eastern regions from December to April with a period of recrudescence in January. The increase in fires during this period could be explained on the one hand by the beginning of the dry season with the movement of the ITD southward, which exposes these regions to the entrance of the harmattan, causing a water deficit that favours the spread of fires, and on the other hand by the humidity level of the vegetation, which is at its lowest level. Similar results have been recorded in the detection of wildfires in Côte d'Ivoire (Bigot et al., 1999). It also appears that the regions most affected by the fires are those of N'Zi and Iffou, this is due to the type of vegetation mainly composed of savannah but also to the abundance of fuel mass in these regions. These results were confirmed by (N'Zué, 2012) which stipulates that savannah areas (North and Central) in Ivory Coast are the most exposed to bushfires, recording the highest number of fires detected. Similarly, it was concluded that the Moronou region was the least affected by fires and burnt areas during the study period; this would be explained by the fact that the distribution of vegetation landscapes in this region is largely composed of dense wet forest formation. Similar results have been recorded in the Nazinga Game Ranch in Burkina Faso (Adouabou et al., 2004). Similarly, studies have generally reported that the low percentage of burned areas in open forests and forest galleries is due to the fact that some pyro-resistant species. According to these authors, these species develop alongside gallery forests as a protective bead, thus slowing the spread of fires (Adouabou et al., 2004 ; Dje et al., 2017). In addition, the wet nature of this type of environment hinders the desiccation of vegetation and therefore the spread of fires.

Finally, a low frequency phase of fires from March to April, characterized by a significant decrease in fire occurrences. This decrease in wildland fire activity is due to fuel depletion and rainfall installation.

4.2.2. Estimation of dry biomass

Analysis of biomass distribution shows that more dry biomass has been located in the Moronou region where fires are rare (dense forests and gallery). On the other hand, less dry biomass is found in the savannah formations of the N'Zi and Iffou regions where fires are more frequent. This could be explained by the type of vegetation in these regions that determines the appearance of fires. Thus, the N'Zi and Iffou regions dominated by savannah formations are the most exposed to vegetation fires, recording the highest number of fires detected. This situation is linked to grass-dominated vegetation in the central-eastern regions as highlighted by N'Zué, (2012) in his study on fire monitoring in Ivory Coast. This could also be explained by the vegetation cover of the regions, most of which are made up of Loudetia simplex grass species, which dry up very quickly a few days after the rains stop, thus encouraging fires to break out. On the other hand, in dense forests and galleries, rivers serve as a natural barrier and would protect most of the species present in these environments from bushfires (Kouadio et al., 2013). This observation confirms the work of Kana & Etouna (2006) in Cameroon, who noted that in the forestry sector, the high humidity and the positive relationship between rainfall and actual evaporation in favour of humidity during the year limit the intensity and spatial extent of plant combustion. Only areas of degraded forests and forest remnants show a relative susceptibility to fire. The analysis of the carpet or herbaceous stratum at the time of vegetation fire outbreaks is noted in the results obtained by Valéa (2016). According to the latter, the latitudinal arrangement of the rains would have an influence on the availability of herbaceous biomass as well as on the structure of the herbaceous mat. This leads to a shortening of the vegetative cycle as the latitudinal progression progresses and finally a thinning of the vegetation cover more or less parallel to the scarcity of rainfall. Hence the location of an abundance of perennial herbaceous plants in savannah formations that promote fire.

4.2.3. Occurrence of wildfires and climate fluctuations

4.2.3.1. The maximum temperature

According to the available data, the study showed that a temperature above 31°C can be used as a threshold value for the maximum temperature content, which allowed fires to occur in the East-Central regions. The maximum of the fires was reached when the maximum temperatures recorded reached 39°C. This could be explained by the fact that during the 2015-2016 season the monthly maximum temperatures (November-December-January-February) were higher than normal, thus creating flare-up conditions. These remarks are confirmed by WMO (2017) in its statement on the state of the world climate, which was very hot in 2015 and 2016, which accentuated the existence of major fires in the regions. Also, according to the latter, the El Niño 2015-2016 episode was the largest compared to the other episodes, thus contributing to the world heat record in 2016. In addition, the N'Zi and Iffou regions were the most affected by the fires compared to the Moronou region. This suggests that there may be a microclimate here that is influenced by various geographical factors (incised valley, river, etc.). However, the decrease in the number of fires recorded when the temperature reached 40°C is explained by the fact that this period corresponds to the beginning of wintering associated with clearing fires.

4.2.3.2. Relative humidity

Analysis of the relationship between relative humidity and fire occurrence showed that more fires were recorded when humidity was below 20%, corresponding to the maximum moisture threshold during the season. This suggests that vegetation has suffered from almost permanent water stress, knowing that the only possible inputs are due to diurnal nocturnal variations in air humidity, as rains are almost non-existent during the November-February period (Belkaïd, 2016; Dje et al., 2017). The minimum average relative humidity values observed during the days of these large fires are about 34%. Thus, the coincidence of these minimum relative humidity values with the start of fires is not automatic. Nevertheless, half of the fires start when the humidity was at its lowest level. The average relative humidity value at the time of their departure is about 60%. However, it is important to note that fires recorded with moisture levels close to 60% could be explained by early fires recorded at the beginning of the dry season when vegetation has not yet been affected by water stress as noted (Mbow, 2000).

4.2.3.3. The rainfall

Analysis of the rainfall data shows a decrease in the cumulative annual rainfall of winter precipitation prior to the fire season for all stations studied. The particularity of this year is the rarity, or even the absence of precipitation during the rainy season (April-May-June). If we look at the monthly precipitation data, we see that the month of January when the fires reached the highest number the difference in precipitation was -100% with long dry sequences. This situation, aggravated by the El Niño 2015-2016 climate phenomenon, has been ranked among the four most powerful since 1950 (WMO, 2017). According to the latter, the El Niño 2015-2016 episode caused a drastic reduction in the volume of rainfall and a high number of fires, thus causing the persistence of drought in West Africa. In the same vein, Dje et al (2017), in their study on the influence of El Niño years on wildfires, showed that maximum intensity El Niño events have a negative impact on rainfall occurrence by disrupting seasonal behaviour. Thus, the shortening of the rainy season during these El Niño periods is a very vulnerable condition for bushfires.

5. Conclusion

Every year bush fires burn several areas in various localities in Ivory Coast causing extensive damage to the agricultural sector and the environment in general. This study is an important contribution to the strategic direction for firefighting, and has focused particularly on the East-Central regions.

The analysis of satellite fire data provided essential information to understand their spatial and temporal distribution, their relationship to climate variables and their effects on natural vegetation. This study showed that during the 2015-2016 season, wildfires occur during the dry season in almost all regions of the East-Central. The distribution and extent of fires are not the same in all regions. These differences are explained by the type of vegetation at the regional level. The fire season 2015-2016 in the regions is limited from November to April. The most affected regions are N'Zi and Iffou. The departments of Bocanda, Dimbokro, Daoukro, M'Bahiakro and Prikro were the most exposed to fire during the vegetation fire season.

From the analysis of climatological statistics, it appears from this study that there is a correlation between climatic variables and bushfires in the East-Central regions. The 2015-2016 vegetation fire season and its severity are therefore linked to climatic variations. The meteorological risk of fires is conditioned by several climatic parameters whose temperature, humidity and rainfall seem to be decisive. In addition, meteorological assistance to the bushfire service requires measuring points in the central-eastern regions. The results of this study show the need to rehabilitate the existing meteorological network in these regions and even to increase its density in order to provide the structures in charge of forest protection with study results that meet local needs. In addition, for proper monitoring of wildfires, it is essential that the forestry services work closely with the climate services.

However, it is important to conduct a fire risk study that would include the El Niño 2015/2016 conditions that prevailed and the length of the drought period on the day of the fire, all integrated into a geographic information system.

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