Octa Journal of Environmental Research
International Peer-Reviewed Journal
Oct. Jour. Env. Res. Vol. 5(2):140-148
Available online http://www.sciencebeingjournal.com

Apr. – Jun., 2017
ISSN 2321 3655

Research Article

Octa Journal of Environmental Research
(Oct. Jour. Env. Res.) ISSN: 2321-3655
Journal Homepage: http://www.sciencebeingjournal.com

Scientific Planet Society
SPS

SATELLITE DATA-BASED ANALYSIS OF VEGETATION FIRES IN THE CENTRAL REGION OF BENIN REPUBLIC

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Received: 14th Mar. 2017 **Revised**: 25th Jun. 2017 **Accepted**: 28th Jun. 2017

Abstract: This research aims at analyzing the vegetation fires using satellite fire hotspots detected by MODIS sensor, the Landsat ETM and NigeriaSat1 imageries. MODIS hotspots were projected to UTM system with WGS84 as ellipsoid and datum. Spatial analyses carried out include the spatio-temporal distribution of fires spots through Kriging techniques and the correlation analysis between the Fire Irradiative Power and the Normalized Difference Vegetation Index (NDVI). Analyses reveal a spatial distribution of fire spots with a slight variation. Years 2002, 2003, 2004, 2005, 2007, 2008 and 2009 recorded high number of vegetation fires above the annual average evaluated at 4317 hotspots. Pearson coefficient revealed the existence of a correlation between the NDVI and fire incidence. When the fire radiative power increases, the density and the greenness of the vegetation expressed by NDVI values, decreases. However, this negative correlation is low and more active in full dry season.

Keywords: Kriging; MODIS; NDVI; NigeriaSat1; Satellite data; Vegetation Fires.

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INTRODUCTION

Vegetation fires known as wildfires play a major role in ecosystem dynamics and pose as an important threat to lives, human and natural resources of fire-prone regions. At the global and regional levels, the causes and consequences of wildfires are typically integrated over large areas and long time periods. Fires may also modify ecosystem composition and functioning. Depending on the fire regimes, burning frequently eliminates plant species and the successional pathways following fire are altered within plant communities (Krefting and Ahlgren, 1974; Noble and Slatyer, 1980; Christensen, 1985). At the same time fire can also have beneficial effects on ecosystem resources. Positive impacts of fire include the management of vegetation structure and composition, the reduction of potentially flammable fuel loads, the improvement of grazing for livestock and pest control (Frost, and Robertson, 1987). The Global Burnt Area Initiative reported that the burnt areas covered a total surface of about 380 millions hectares in 2000 (Gregoire et *al.*, 2002). This report pointed Africa as the most affected continent in that year. At the scale of West Africa, the distribution of fires forms a delimited and continuous space of opened savannahs and light forests. Recent studies indicated that the high rate level of ozone and the frequency of rain acids on tropical forests are caused by the emission of gas generated by vegetation fires and the half of the carbon dioxide from fires is coming from Africa, and is equivalent to the rest of the world (PNUD/UNSO, 1990). In the Republic of Benin, particularly in the northern part of the country, vegetation fire is part of tradition heritage that is quietly difficult to abandon (Tandjiékpon, 2001). The rural population uses fire (bush burning) as land clearing tools for agricultural purposes, pasture management for breeding and hunting. It has been noted that about 95% of wildfires are human-caused and the habitual period for setting fires extends between November and May. This period is of high temperatures (30 to 35°C), which rises generally from January onwards combined with the hot and dry harmattan winds blowing from North to South between December and March. The majority of damaging fires are observed during that critical period of the dry season. It is observed that the area above 8° N latitude in Benin is more exposed to wildfires, mainly because of cotton and yam production. These two crops require high soil fertility and more space, so farmers clear new forestland each year. According to Linsoussi (2011), 13 to 23% of the national territory is burnt each year and this is related to the rainfall regime. The consequences cause serious environmental damages notably; the decrease in the quality of the air, the reduction of the soil fertility with the burning of the biomass which is not integrated to the soil, reducing the quantity of humus. Also the nutrients of the ashes coming from the burnt vegetation are taking away by wind and water. Sometimes these fires escape all controls and devastate farmlands and plantations (Thamm, 2008). However, at the landscape level, each wildfire is a distinct event with its own history, ignited and burning under specific fuel and weather conditions, ultimately leading to unique social and ecological impacts. The identification of individual fire events has been acknowledged as necessary to better understand how fire extent and frequency affect global environmental processes.

Characterizing individual wildfires is relevant to identify associated causes to understand the factors controlling fire occurrence to estimate fire risk, characterize fire regime, to understand the complex interactions between fire spread and its main drivers to estimate carbon emissions and assess fire-related impacts. Improving the quality and quantity of the information regarding individual wildfires has important implications for fire suppression and management, and for improvement of prevention policies. To establish sound fire management programs as part of an integrated ecosystem management strategy, the contrasting effects of fires need to be considered and evaluated and the resulting information need to be incorporated in the analysis of benefits and costs. As part of developing this management strategy it is important to understand the drivers of land cover and land use change and the causes of fire. The impact of fire in changing biodiversity needs to be understood at the local and landscape scale. Similarly the impact of fire on modifying ecosystem composition and functioning modifications need to be understood. The present paper aims at analyzing the spatio-temporal variability of vegetation fires in the Central part Benin. First of all, the magnitude of fires will be appreciated in time and space using MODIS hotspots. Secondly, its impacts on the land use/cover especially to the vegetation will be assessed and appropriate recommendations will be made for a better management of wildfire in the centre of Benin.

Study Area

The study area is the centre of Benin, comprising the province of Collines, a part of Borgou, Zou, Plateau and Couffo provinces. The area extends between 1°38' and 2°46' of East longitudes and between 7°30' and 9°00' of North latitudes. Administratively, it covers entirely the districts of Savè, Ouèssè, Dassa-Zoume, Glazoué, Bantè and Savalou, and some parts of Tchaourou, Djidja, Ketou, Aplahoué, Covè and Zagnanado districts (Figure 1). It is located within a transition climatic zone between the subequatorial and sudanian climates (Bokonon-Ganta, 1987). The rainfall pattern is straddling on bimodal distribution of the south and the unique rainfall modality of the North. The total annual rainfall varies between 900 and 1200 mm. The temperature and its monthly mean values oscillate between 24 and 32°C (at Savalou). The months of February and March are generally hotter while August displays low temperatures. The vegetation presents a various types of formations from dense forest to farmlands and fallow lands. The landscape is dominated by shrub and woody savannah, farmlands and light forests (Sepulchre *et al.* 2007).

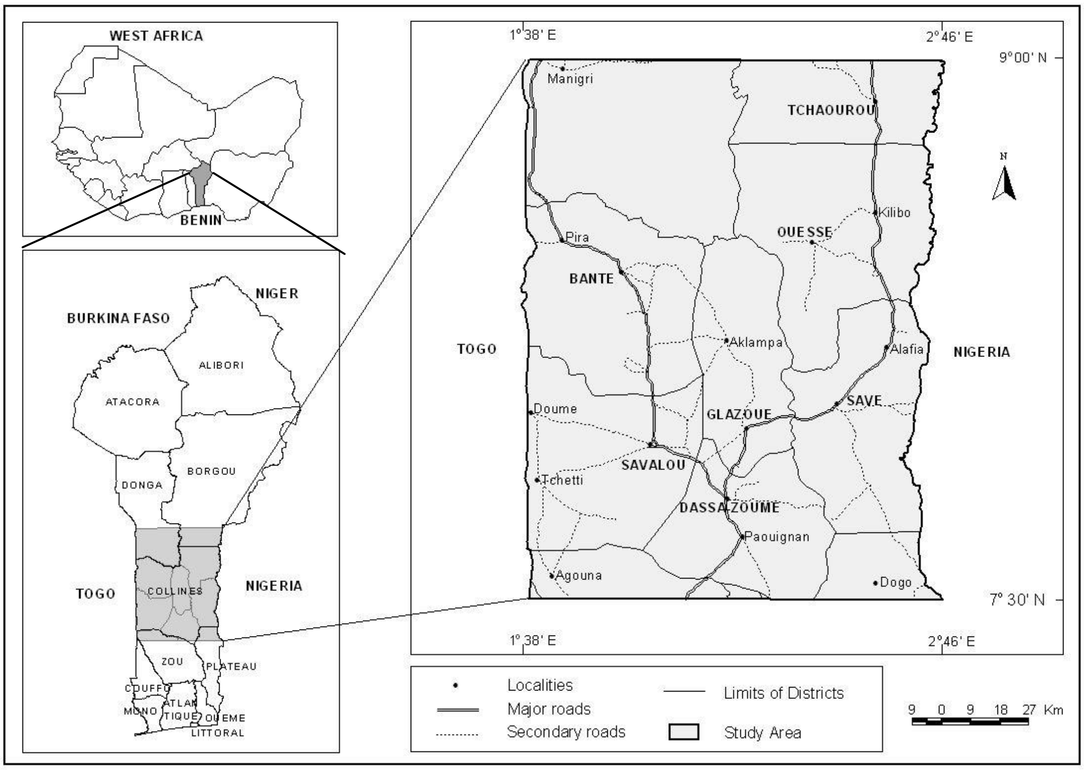


Figure 1. **Study area Map**

EXPERIMENTAL

Data Used

The data used for this study comprise the fire MODIS (Moderate Resolution Imaging Spectroradiometer*)* hotspots acquired from November 2000 to May 2010 which was obtained from the department of Geography, University of Maryland. This sensor is mounted on board of Terra and Aqua satellites and is equipped with a thermal system that measures the temperature on the earth surface (Justice *et al.,* 2002; NASA/University of Maryland, 2002; Davies *et al*., 2009). If the temperature at a point is above a threshold, MODIS considers this particular location as an active fire point (Langner et Siegert, 2008, Giglio et al., 2003). Satellite data over three periods were also used. These are Landsat TM (Thematic Mapper) of 1986, Landsat ETM + (Enhance Thematic Mapper) of 2000 and NigeriaSat1 of November 2006 (Table 1).

Table 1. Satellite data used and Their Characteristics

Satellite	Sensor	Resolution	Scenes	Date of acquisition
Landsat 5	TM (Thematic Mapper)	28,5 m	P192R54 P192R55 P191R55	13/01/1986
Landsat 7	ETM (Enhance Thematic Mapper	28,5 m	P192R54 P192R55 P191R55	13/12/2000
NigeriaSat1	NigeriaSat-1 (Standard DMC sensor)	32m	Column : 16151 Row : 9902	15/11/2006

Methodology

Hotspots Data Processing and Trend Analysis

The MODIS fire points obtained in form of Shapefile were re-projected in the UTM system using the WGS 84 as ellipsoid and datum in order to overlay the output on the land use and land cover maps of the study area. The analysis of the spatial distribution of hotspots helps in locating and presenting the area of fire occurrences using Kriging techniques. These areas will necessitate a follow up and more surveillance in fire management. Kriging presents an aggregate of fire points and depicts areas of dense fire activities and areas where fires occurrences are less dense (Valea, 2005). The logarithmic trend of the evolution of fire hotspots since November 2000 to May 2010 was assessed to clearly show years where the frequency fire occurrences was high. Augmented Dickey Fuller Test was used to appreciate the stability in time and the existence of a trend and in vegetation burning using STATA statistical software. The data used at this effect was the chronological series of the number of fires detected par MODIS sensor from November 2000 to May 2010.

Analysis of Fire and Vegetation Dynamic

In order to study the relationship between fire and vegetation, a Pearson correlation analysis was done between the Normalized Difference Vegetation Index (NDVI) and the Fire Irradiative Power (FRP). Pearson correlation coefficient determines the existence of a correlation between two variables. For example, the behavior of a variable is examined and studied when the other variable increase or decrease. It gives insight on the nature of the relationship, the intensity and the sense (Held, 2010).

RESULTS AND DISCUSSION

Trend and spatio-temporal occurrence of vegetation fires in the centre of Benin

Annual and seasonal bushfires are observed in the central region of Benin Republic. The analysis of the MODIS hotspots revealed an annual spatial distribution of fires with a slight variation. The years 2002, 2003, 2004, 2005, 2007, 2008 and 2009 recorded a high number of fires largely above the annual average estimated at 4317 hotspots. The highest number recorded from November 2000 to May 2010 was observed in December 2002 (Figure 2). The logarithmic trend shows a quiet increase of the hotspots with a progression in serrated way. This explains the low value of the coefficient of determination (R^2=0.0128) between the variables. The variation in vegetation burning reveals that explanatory factors of fires are not constant throughout the year. According to the monthly and decennial variations showcased in figure 2, fires are intensified in January and December. This is an evidence that fire activities are related to the dry season which extends from November to March in the centre of Benin. The augmented Dicker Fuller test has shown that fires are not stationary in time. The calculated Z(t) value (-6,309) is lesser than the critical values obtained in each thresholds (tableau 2) indicating that there is no uniformity in time of the fire phenomenon. The test of the existence of trend shows an increase in fire activities in a non significant way (t=0.68, which is lower than 1), confirming the quiet logarithmic trend observed in Figure 2.

Analysis of the Spatial Density of Fire

Figures 3a and 3b show the densities and the areas of concentration of fires in the study area. The spatial distribution indicates that fires are intensified as one goes towards North West of the study area. The details of the distribution are presented as follow:

- In 2000-2001, fires were concentrated in Bassila district, the north of Glazoué District, the west of Tchaourou and Ouèssè Districts and the area defined by the triangle Savalou-Tchetti and Doume and then the south of Save District.
- In 2002, the density was high in Bassila district, Ouèssè North West and Tchaourou west.
- In 2003, a dense blazing corridor oriented SW – NW was observed also in Bassila District. In 2004 that corridor was enlarged and has occupied the whole west of Basila District.
- In 2005 and 2006, the trend was the densification of fire in the same Bassila District but an aggregate was observed in the south of Ouèssè in 2005.
- In 2007 and 2008, the same trend was observed. But in 2008, the area witnessed some new aggregates of fires in South precisely at Paougnan west in Dassa-Zoume District and in the south of Save towards the border with Ketou district.
- In 2009, the northern part of the study area was mostly affected. But from January 2010 to May 2010, only one

aggregate was noted in the district of Bantè, precisely at Pira town.

The overall analysis revealed that Bassila district remained the most affected area where fires are always occurring in the study area. This district revealed a permanent constant in the density of vegetation fires. Concerning this peculiarity of Bassila district, it has to be noted the presence of three important Forests reserves namely Bassila forest, Monts Kouffé forest and a part of Wari-Maro reserved forest. These forests constitute a very important reserve of game animals that attract hunters during the dry season. Therefore, hunters used fire as hunting tools and they constitute the main factors of bushfires in the study area, followed by a cattle transhumance and then crop farmers.

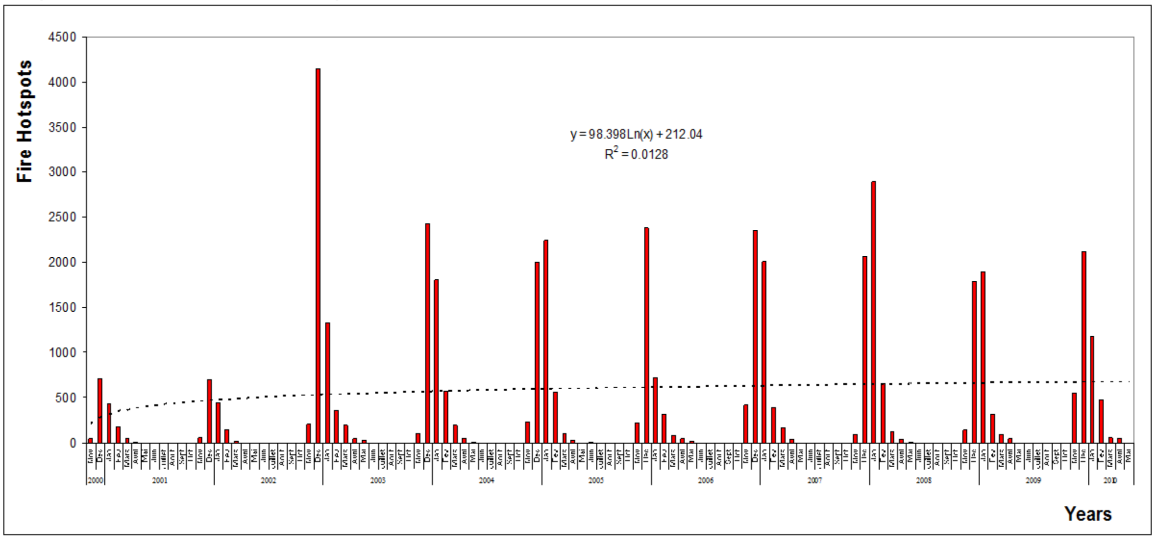
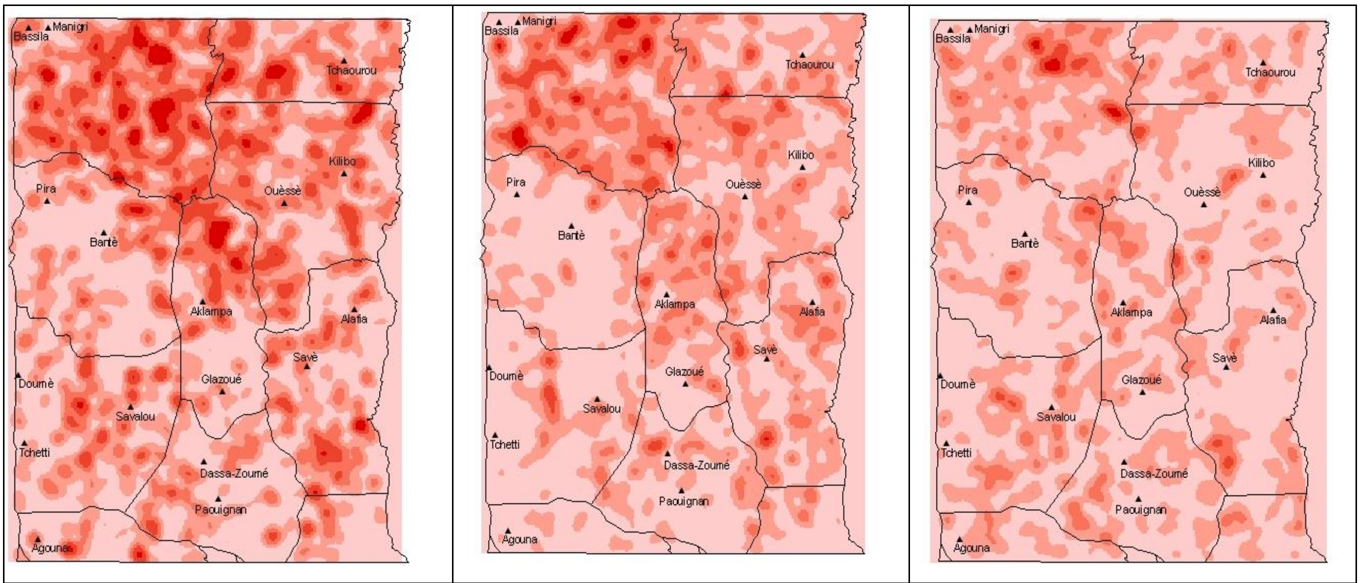
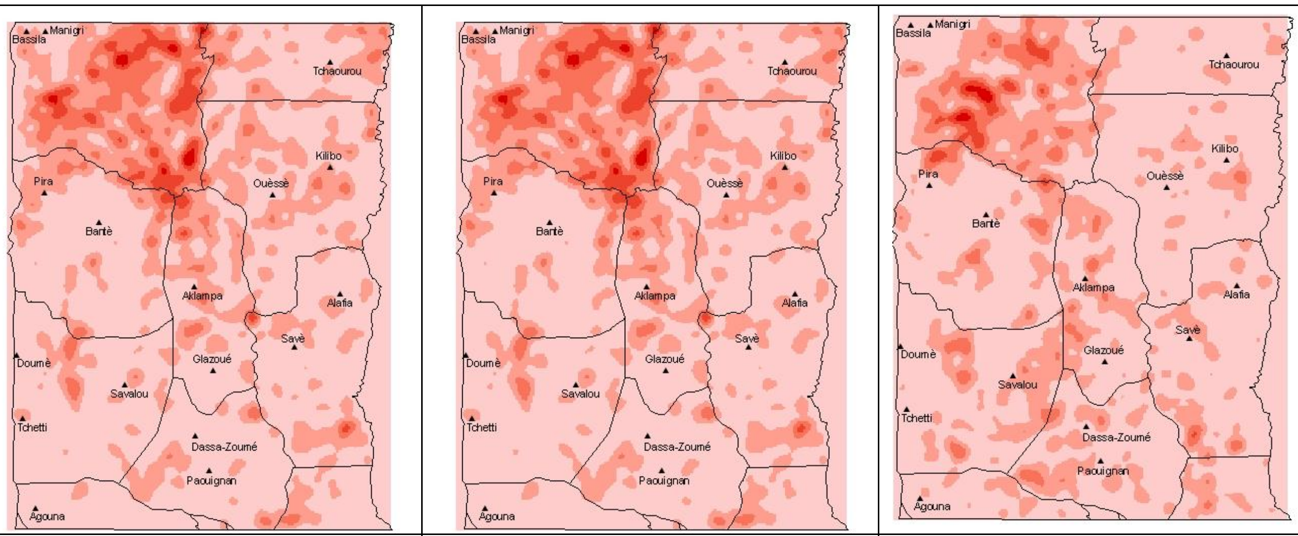


Figure 2. Figure Temporal Evolution of Fire spots from November 2000 to May 2010



2000 – 2001	2002	2003



2004	2005	2006

Figure 3a. Spatial Densification of Fire from November 2000 to 2006

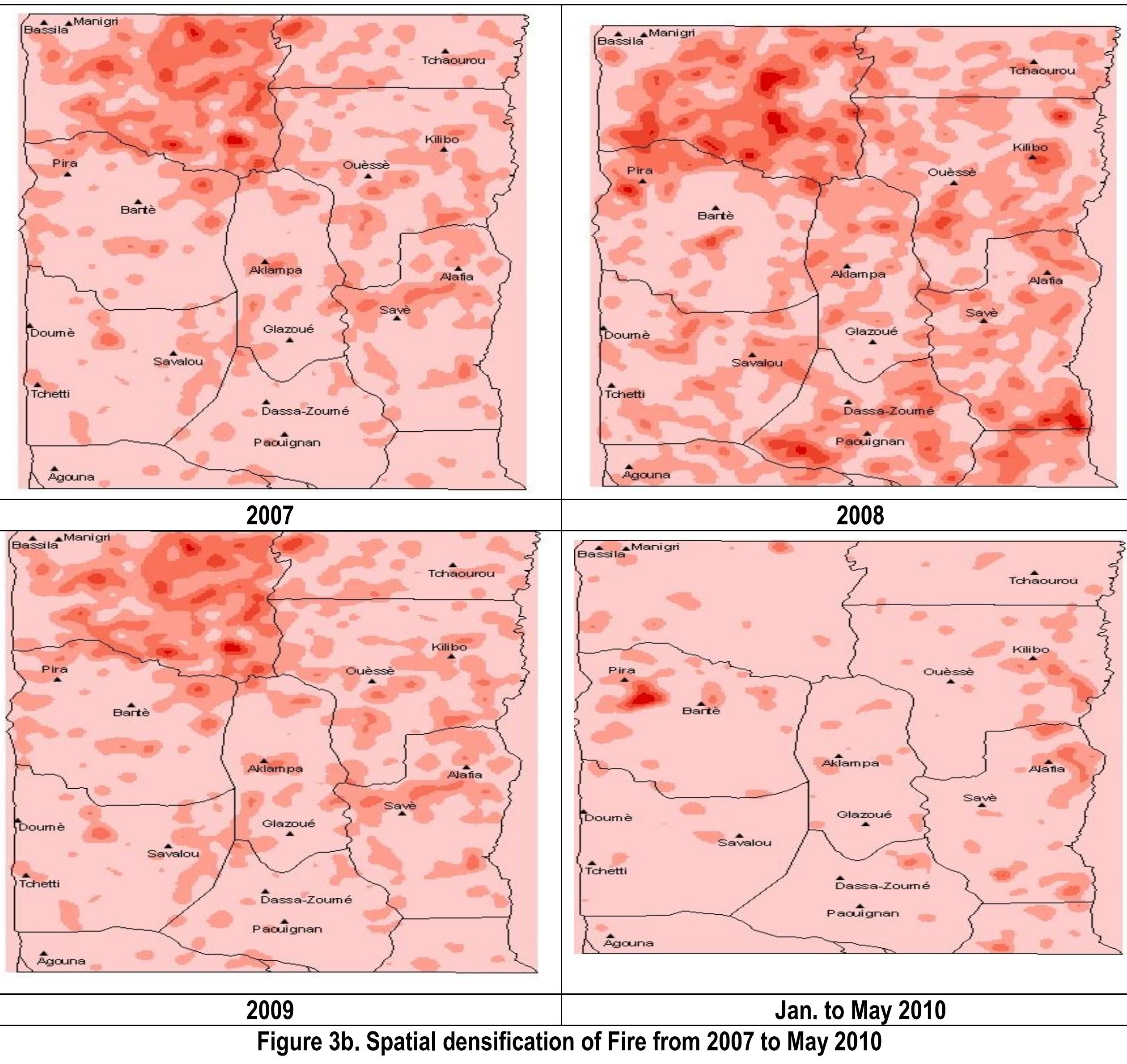


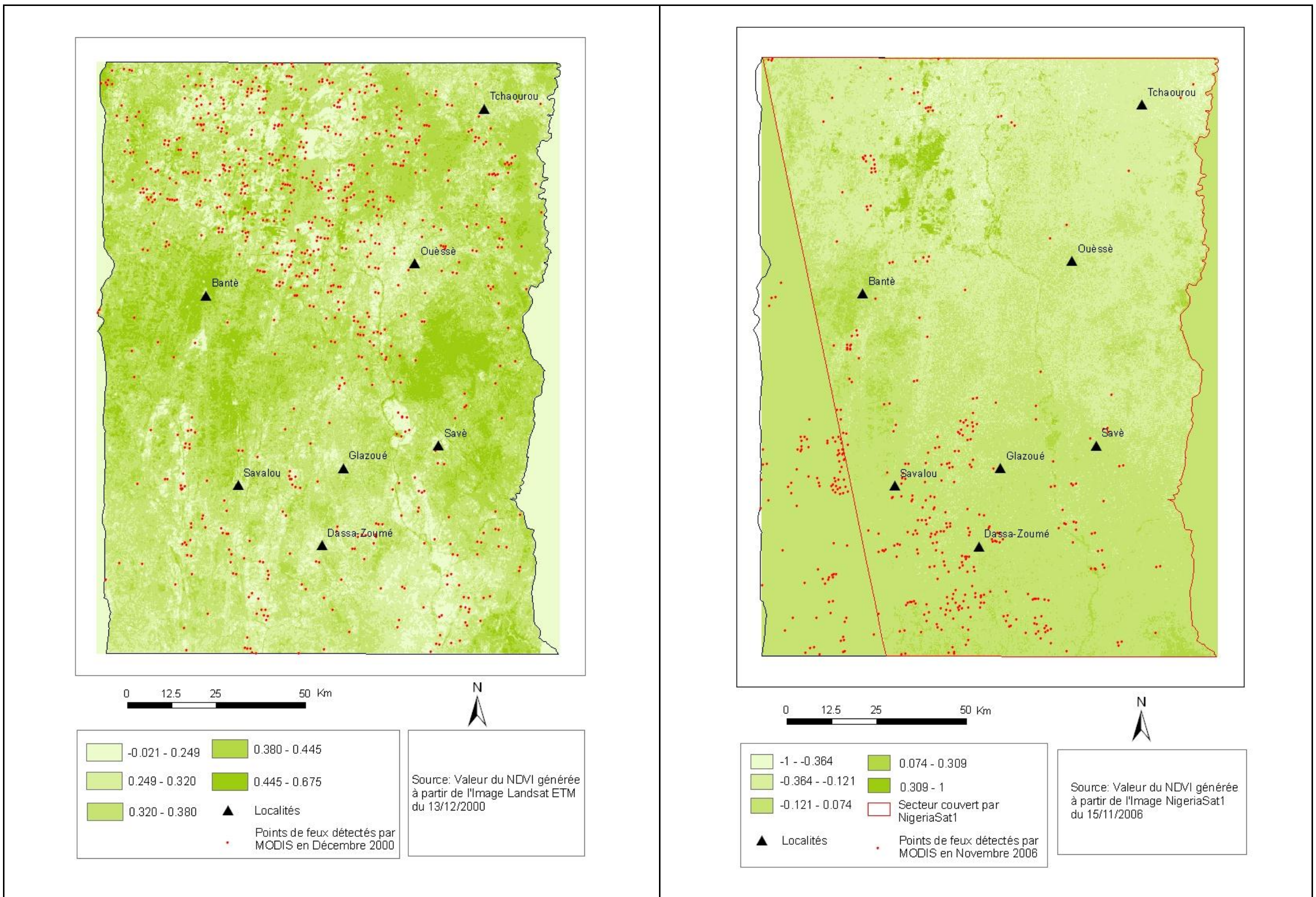
Figure 3b. Spatial densification of Fire from 2007 to May 2010

Table 2. Augmented Dickey Fuller test of Stability and Existence in Fires Occurrences

Test Statistic		Interpolated Dickey-Fuller					
		1% critical value		5% Critical value		10% Critical value	
Z(t)	***-6.309***	-4.036		-3.448		-3.148	
D Freq		**Coefficient**	**Std. Error**	**T**	**P> |t|**	**95% conf Interval**	
L1		-0.758569	0.1202422	-6.31	0.000	-0.9969351	-0.5202029
L2		0.31472	0.1014908	3.10	0.002	0.1135263	0.5159137
L2D		0.0545981	0.0965349	0.57	0.573	-0.136771	0.2459673
Trend		1.343444	1.973266	***0.68***	0.497	-2.568327	5.255214
Constance		206.7966	134.4577	1.54	0.127	-59.75016	473.3434

Vegetation Dynamic and Fire Radiative Power

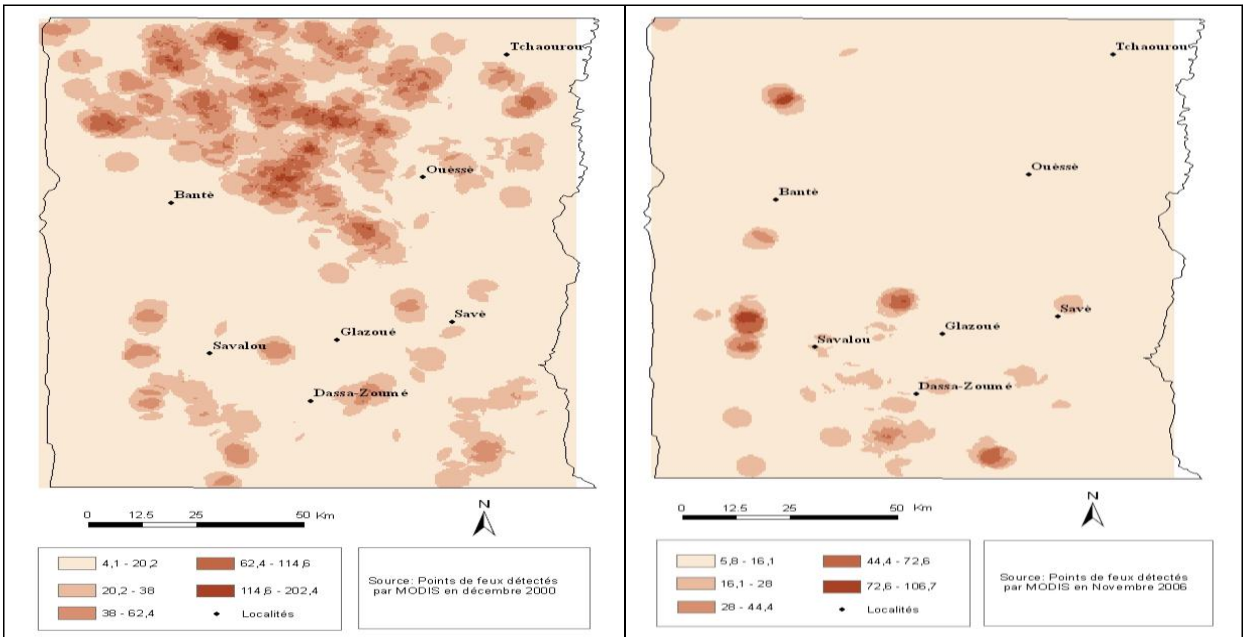
The normalized vegetation index (NDVI) generated in December 2000 and November 2006 shows a disparity in the appearance of the vegetation. In 2000, there were some parcels of dense formations shown by bold green even in the dry season, while in November 2006 these parcels have been fragmented. After overlaying the fire hotspots on the different NDVI maps, it was observed a high densification of these fires in December than in November (Figure 4).



2000 | **2006**

Figure 4. Normalized difference Vegetation Index (NDVI) and Hotspots Fires

The Fire Irradiative Power (in MW) showing the quantity of energy or fuel released on the vegetation is presented in Figure 5. This power is intensive in December and less in November. The irradiative values are high in the north in 2000 while the concentration is less dense in 2006. The correlation analysis between the NDVI and the FRP in 2000, revealed a correlation coefficient of -0.089 in December, which indicate the existence of a relationship between the vegetation and the fire irradiative power. This correlation is low, negative and significant at 0.05 alpha levels, which shows that as the fire radiative power is increasing, the NDVI values are decreasing, evidence of the reduction of the vegetation density. The same analysis was conducted for November 2006. The major constraint is the reduction in the size of the sample due to the fact that the concerned period is the beginning of the bush burning activities. There was no intensity, as this month constitutes the transition period from the rainy to dry season. It is also observed that only targeted and early fires are set to protect properties like farms, plantations and stocks. Nevertheless, the analysis revealed an R value of -0.008, indicating that at that moment of the year, the correlation is negative but very low.



2000	2006

Figure 5. Fire Irradiative Power in December 2000 and November 2006

In general, there is a correlation between the behavior of the vegetation and fire. When the fire irradiative power increases, the density and the greenness of the vegetation expressed by NDVI decrease. It has to be noted that this negative correlation, though effective, is low and more active in dry season. Therefore it is evident that fires play a partial role in the degradation of the vegetation, implying that there are some other factors of degradation of the vegetation components of the land use and land cover.

CONCLUSION

The analysis of the spatio-temporal occurrences of vegetation fires in the central region of Benin revealed a serrated variability. The peak was observed in December 2002. The use of MODIS hotspots has shown the possibility of a daily, monthly and annual monitoring of vegetation fire. The paper shows that fires between November 2000 and May 2010 mostly affected Bassila district. Fires are considered as phenomena with multiple factors imputed by the hunters and transhumant cattle breeders in the study area. Their consequences are always obvious because the damages caused are enormous. At the same moment, fires are used by farmers as a work and monitoring tools: land clearing, hunting tools, new pastures generation tool, properties protection tools, especially when they are set early in the year before the commencement of the dry season. This study also highlighted that fires play a partial role in vegetation degradation in the study area. Concerning Bassila district that has been revealed as the fire setting permanent area in the centre of Benin, there is a need for an intensive sensitization of actors involved in order to limit the impact of these fires on vegetation especially when they are used lately in the dry season. It would be necessary to reactivate the existing alert and local sensitization brigade put in place in the frame of the PAMF (*Projet d' Aménagement des Massifs forestiers des Monts Kouffé, Agoué et Wari Maro*) for the protection of the forest reserves again devastating and degradation fires. For the general public, emphasis should be laid on the early fires to control the biomass and avoid propagation of fire risks into farms and other properties.

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Sources of Support: None.
Conflict of interest: None. Declared.