Regionalization of a Remote Sensing based Spatial Decision Support System for Bush Fire Management in Benin

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To my parents . . .

Abstract

Wildland fire agencies officers need objective and systematic information to make effective decision on fire management. Getting such information is usually challenging especially in developing countries where the required infrastructures or skills are not always available. Recent developments in the assessment of bush fires using remote sensing techniques and the availability of such results enable a systematic study of fire distribution and regime on different spatial scales. In this dissertation, we propose a development of a spatial decision support system for Bush fire monitoring called FIMAT (FIre MAnagement Tool), as well as a case study using the tool developed for Benin. The purpose of this study was (1) to grasp the theories of fire ecology and (2) state-of-art methods on vegetation fire assessment, (3) to develop a Spatial Decision Support System for Fire Management and (4), to regionalize its use to Benin for spatial and temporal fire distribution description.

FIMAT is developed in Java using libraries such as Geotools, Jhdf. The fundamental data used by this system are MODIS burned area level 3 product along with auxiliary layers of geographic information. The MODIS burned areas product is derived from processing of combined MODIS-TERRA and MODIS-AQUA 500m land surface reflectance data using the Bidirectional Reflectance Distribution Function (BRDF) in a model-based change detection approach. This algorithm approximates the dates of burning by locating the occurrence of rapid changes in daily MODIS reflectance time series. FIMAT encompasses many processing and report functionalities. A data management system can automatically downloads the required fire data from MODIS Dataserver, if they are not available locally. A fire statistics calculator can generate the necessary information at small spatial scales (e.g municipality) from the original HDF data tile and save the result as Geotiff raster or other file formats. A map editor displays the processing results as a map along with additional layers. The created map can be customized by using the interactive integrated style editor and graphic editor and a chart editor shows generated statistics. Documents can be added to the project in Pdf format and viewed with the integrated Pdf viewer. The textual and graphical information generated by this monitoring tool can help decision makers to monitor and assess bush fire in simple way without them being necessarily specialists in Programming or Geographic Information Systems. It is an application with a simple user graphical interface. It is useful as a tool for operational assessment of compliance to the laws and arrangements. FIMAT has the following advantages over available tools (e.g Web Fire Mapper)

- FIMAT can operate off-line;
- it permits mapping of additional data layers;
- it includes graphical editor and other useful reporting systems;
- the maps and charts generated are highly customizable;
- it offers more analysis and output options;

- it allows assessment at subnational level (e.g communal level).

From the investigations on spatial and temporal distribution of vegetation fire in Benin, it results that fire is a recurrent phenomenon in this region. It distribution in time and space follows approximately the same pattern over the studied period 2000-2009. Fires start usually in October and last until April/May with a maximum in December. Most of the burnings occur once at every location but some areas can burn two or three times a year. Those multiple burned areas are generally in protected areas where the fuel load is important and the vegetation more continuous. The multiple burned areas are usually extensions of late burned areas on early burned areas in their neighbourhood.

Zusammenfassung

Entscheidungsträger wie Behörden und Entwicklungsgesellschaften benötigen objektive und systematische Informationen um Entscheidungen für ein effektives Feuermanagement treffen zu können. Eine raumzeitliche Erfassung der Feuergefahr ist besonders in Entwicklungsländern, in denen es oft an den benötigten Infrastrukturen oder Ausbildungen mangelt, eine Herausforderung. Aktuelle Entwicklungen in der Erfassung von Buschbränden bauen auf Fernerkundungsverfahren, durch deren Ergebnisse systematische Studien über Feuerausbreitungen und -regime auf verschieden Skalenebenen möglich werden. In der vorliegenden Dissertation wird die Entwicklung des räumlichen Entscheidungs- und Unterstützungssystems FIMAT (FIre MAnagement Tool) für Buschfeuer und mit ihm bearbeitete Fallstudien für Benin vorgestellt. Die Ziele der Arbeit sind (1) Verstandnis der Feurökologie und (2) Untersuchung aktueller Methoden zur Feststellung von Wald/Buschbränden, um (3) ein räumliches Entscheidungs- und Unterstützungssystem für das Feuermanagment zu entwickeln, welches (4) auf den Benin regionalisiert angewandt wird, um die dort herrschende zeitliche und räumliche Brandentwicklung zu beschreiben. FIMAT wurde in Java entwickelt und nutzt bestehende Bibliotheken wie z.B. Geotools. Die grundlegenden Eingangsdaten des Systems sind das MODIS Burned area Level 3 Produkt in Verbindung mit zusätzlichen Geoinformationsdaten. Das MODIS Burned area Produkt ist ein modellbasiertes "Change Detection" Produkt basierend auf MODIS-TERRA und MODIS-AQUA (500m Auflösung) abgeleiteten der bidirektionale Reflektanzverteilungsfunktion. Dieser dabei verwendete Algorithmus approximiert den Zeitpunkt der Buschbrände über das Auftreten schneller Änderungen in den täglichen MODIS Reflektanzzeitreihen. FIMAT umfasst viele Bearbeitungs- und Berichtsfunktionen. Ein Datenmanagementsystem ermöglicht es die benötigten Daten automatisch von dem MODIS Datenserver online herunterzuladen insofern sie nicht lokal verfügbar sind. Statistische Operationen zur Ermittlung der von Feuer die Berechnung der nötigen Informationen auf kleiner räumlicher Ebene (Gemeindeebene) aus den originalen HDF Bildkacheln sowie deren Speicherung als Geotiff Raster oder in anderen Datenformaten. Ein Karteneditor stellt die Ergebnisse kombiniert mit zusätzlichen Layern dar. Die so produzierten Karten können mit einem integrierten Editor individuell angepasst und die statistischen Daten über ein Diagrammeditor visualisiert werden. Weiter Zusatzdokumente können in dem Projekt über einen integrierten Pdf Viewer hinzugefügt und betrachtet werden. Entscheidungsträgern können mit dem hier vorgestellten Monitoring-Tool graphischen und textlichen Informationen erhalten und verarbeiten, die ihnen bei der Überwachung und Bewertung von Buschfeuern helfen. Das Programm ist einfach zu bedienen und erfordert keine speziellen Programmierfähigkeiten oder Kenntnisse Geographischer Informationssysteme (GIS). Es kann als Kontrollmedium der Staat und Behörde eingesetzt werden, um die Einhaltung von Gesetzen und Abkommen zu überprüfen. In Vergleich zu globalen Ausätzen zum Feuermonitoring (e.g FIRMS) besitzt der für Benin regionalisierte FIMAT Ausätz die folgenden Vorteile:

- FIMAT kann in off-line Modus arbeiten

- es erlaubt das Kartieren von zusätzlichen Daten layers
- es beinhaltet einen graphischen Editor and weiter nützliche Funktionen
- erstellte karten and Diagramme sind flexibel anpassbar
- es bietet weitere analyse und Ausgabe Optionen
- es ermöglicht die Untersuchung auf subnationalem level (z.B Kommunales Level)

Auswertungen der räumlichen und zeitlichen Verteilung von Wald- und Buschbränden in Benin zeigen, das Feuer ein aktuelles und wiederkehrendes Phänomen in dieser Region ist. Die raum-zeitlichen Verteilung folgte im Beobachtungszeitraum 2000 - 2009 den gleichen Mustern. Das Auftreten der Feuer beginnt normalerweise im Oktober und endet im April bis Mai mit Maximum im Dezember. Die meisten Brände treten nur einmal in einer bestimmten Region auf, jedoch gibt es Gebiete in den es zwei bis dreimal pro Jahr brennt. Diese mehrfachen Brände in einer Region treten im Allgemeinen in geschützten Gebieten auf, welche eine dichtere Vegetation aufweisen. Bei Flächen mit zwei oder mehrfachen Auftritt der Brände handelt es sich zu meinst um Gebiete älterer Brände die an Gebiete jüngerer Brände grenzen.

RESUME

Les agents des services de gestion des feux de végétation ont besoin d'information objective et systématique pour la prise de décision efficace sur la gestion de ces feux. Obtenir ces informations est généralement difficile en particulier dans les pays en développement où les infrastructures nécessaires ou les compétences ne sont pas toujours disponibles. Les développements récents dans l'évaluation des feux de brousse en utilisant des techniques de télédétection et la disponibilité de tels résultats permettent une étude systématique de la distribution et du régime des feux à différentes échelles spatiales. Dans cette thèse, nous proposons un développement d'un système spatiale d'aide à la décision pour la surveillance des feux de brousse appelé FIMAT (FIre MAnagement Tool), ainsi qu'une étude de cas d'utilisation de l'outil développé pour le Bénin. Le but de cette étude était (1) de saisir la théorie de l'écologie du feu et (2) de faire une revue des méthodes actuelles sur l'évaluation des feux de végétation, (3) de développer un système spatiale d'aide à la decision pour la gestion des incendies et (4) de régionaliser son utilisation au Bénin.

FIMAT est développé en Java en utilisant des bibliothèques comme Geotools et Jhdf. Les données fondamentales utilisées par ce système sont les produits de zones brulées de MODIS, Level 3 avec des couches géographiques auxiliaires. Le produit MODIS des zones brûlées provient du traitements combinés des données de réflectances MODIS-TERRA et MODIS-AQUA à la resolution de 500m à l'aide de la methode directionnelle réflectance (BRDF) approche fondée sur un modèle de détection des changements. Cet algorithme détermine la date approchée de l'incendie en localisant les changements rapides survenus dans la série quotidienne de réflectance de MODIS. FIMAT englobe de nombreuses fonctionnalités de traitement et de generation de rapports. Un système de gestion de données peut automatiquement, du serveur de MODIS, télécharger les données d'incendie réquises, si elles ne sont pas déjà disponibles localement dans le repertoire de l'utilisateur. Un générateur de statistiques d'incendie peut produire les informations nécessaires à petites échelles spatiales (municipalité, par exemple) à partir des données HDF d'origine et enregistrer le résultat sous forme raster Geotiff ou autres formats de fichier. Un éditeur de carte affiche les résultats du traitement sous forme de cartes avec des couches supplémentaires. La carte créée peut être personnalisée en utilisant l'éditeur de style interactif intégré et un éditeur graphique montre les statistiques générées. Les documents peuvent être ajoutés au projet en format Pdf et visualisés avec l'afficheur Pdf intégré. Les informations textuelles et graphiques générées par cet outil de surveillance peuvent aider les décideurs à suivre et évaluer les feux de brousse de manière simple sans qu'ils soient nécessairement des géographes ou spécialistes de la programmation. Il s'agit d'une application avec une interface utilisateur graphique simple. Il est utile comme outil pour l'évaluation opérationnelle de la conformité aux lois et arrangements. Comparés à d'autres systèmes existants, FIMAT présente les avantages ci-après.

- FIMAT peut être utilisé hors connection Internet;
- il permet la cartographie de couches additionnelles de données;

- un editeur graphique et d'autres systemes de generation de rapport y sont inclus;
- les cartes et graphiques générés sont personnalisables;
- FIMAT offre plus d'option d'analyse et d'output;
- FIMAT permet des operations au niveau sous-national (par exemple niveau communal).

De l'étude de la distribution spatiale et temporelle des feux de végétation au Bénin, il résulte que le feu est un phénomène récurrent au Bénin. Sa répartition dans le temps et l'espace a suivi à peu près la même tendance sur la période étudiée 2000-2009. Les incendies commencent généralement en octobre et durent jusqu'en avril /mai. La plupart de ces incendies se produit en décembre. La plupart des incendies se produit une fois à chaque endroit, mais dans certaines régions il peut brûler deux ou trois fois par an. Ces zones à multiples incendies se retrouvent généralement dans les aires protégées où la charge de combustibles est importante et la végétation plus continue. Elles sont essentiellement des extensions des feux tardifs sur les zones environnantes brûlées plus tôt.

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Chapter 1

Background and rationale of a Spatial Decision Support System(SDSS) for bush fire management in Benin

1.1 Fire: an ecological key parameter

Fire, affecting many ecosystems all around the world,is a matter of great concern. Bond and van Wilgen (1996) perceived fire as the most ubiquitous terrestrial disturbance after urban and agricultural activities. The Joint Research Centre(JRC) of the European Commission,through its first global survey of burned areas, estimated that 350 million hectares of global land were affected by fire in 2000. It showed Africa as the most fire-prone continent with 2.3 million km^2 or 64 percent of the global total (JRC-EU, 2005). Most of the burned areas are located in Sub-Saharan Africa (FAO, 2007a). Bushfire has been broadly explored by many researchers(Pyne et al., 1996; Bond and van Wilgen, 1996; Goldammer, 1990). It is described by scientific community as the driving factor of the composition and structure of the savanna ecosystems in that area (Andersen et al., 2003; Bond and van Wilgen, 1996) . Authors agree that the maintenance and conservation of African savanna ecosystems depend on fire incidence(Aubréville, 1947). Anthropogenic factors are usually listed as the main causes(Ampadu-Agyei, 1988; Crutzen and Andreae, 1990). These factors are either intended or due to negligence of people. Indeed, while lightnings could generate fire in other areas, it is widely recognized that this source of fire is seldom in west African savannas. Extensive use of bushfire is rooted in socio-economic life of rural population in West Africa. People lit fire in the bushes for clearing land for cultivation, hunting games, rejuvenation of grassland forage. Besides such uses, malicious setting of fire to bushfire have been reported. Moreover, unintentionally large bushfire are generated by cigarette butts or uncontrolled cooking fires. Fires are also made for management purpose. This "culture of fire" as named by Ampadu-Agyei (1988) is common to most countries in this area. Even if it should be recognized that fire is a key element in the good functioning of some ecosystems, damages caused by bushfire are various and huge although unquantified. These include modification of the structure of soil and local climate. Bushfires affect land use, productivity, carrying capacity and biodiversity (Danthu et al., 2003; FAO, 2007b). They are a major driving factor of surface change and happening in many areas. These changes have significant effects on different spheres (Bucini and Lambin, 2002). It affects hydrologic, biogeochemical and atmospheric processes. This can lead to migration and food insecurity (Doevenspeck, 2004). Therefore a sustainable fire managing policy is an important challenge. Even though many bushfires management policies have been elaborated, fires are still occurring today. Vegetation fires are of increasing public concern revealing in that many governments of West-Africa rise expenditures on bush fires management systems. The common used strategy is so-called prescribed fire aiming to alleviate the damages that can induce possible bushfires coming later in the dry season. This policy, introduced in the colonial period is of a common use now (Laris and Bakkoury, 2008). This solution could be yet very effective, if the pattern of fire is well known. Although many countries publish information on bushfire, there still remain discrepancies between ground survey data and satellite-derived data . The collection of reliable ground data is rather impossible in vast area of Africa (FAO, 2007a). Protected area managers need fire information to be delivered while fires are still burning, with minimal file sizes and in easy-to-use formats. In addition, in developing countries context the needed data should be affordable. Satellite remote sensing provides the unique reliable way to monitor fire at regional and global scale. Recent developments in the assessment of bush fires using remote sensing (RS) techniques and availability of such results enable a systematic study of fire distribution and regime on different spatial scales. Availability of free regular daily records on fire information from the Moderate Resolution Imaging Spectroradiometer (MODIS) since the launch of NASA's Terra and Aqua satellites in late 1999 enhances meaningful times series analysis. Moreover, recently the burnt area products derived from these datasets, have become available. The sufficiently long observational record enable calculation of aggregates enabling the analysis of fire pattern. Thus, it is now possible to detect nearly real time burnt areas and to analyze fire pattern. That could be used to update the parameters required for valuable objective decision making process of fire managers. In this dissertation, we propose an implementation of a decision support system (DSS) based on Geographic Information System (GIS) and Remote Sensing (RS) for bush fire monitoring, as well as a case study using the tool developed for Benin.

1.2 "Culture of bushfire"

The republic of Benin is one of the countries within the fire-prone area of Africa. Recently the Ministry of natural protection has elaborated the Benin's fire management strategy document (DGFRN, 2008) and has listed the main activities related to fire in Benin. The document results from a two stage work. The first stage was a participatory regional diagnostic study. The country was divided into seven study units made up with groups of departments. Fire assessment is done in each unit. This assessment involved the study of the vegetation fire situation in each unit, the identification of stakeholders in the management and their capabilities. The investigation was validated at unit, national and relevant departments of FAO levels. The second step was the edition of the national strategy document of fire management. Fire is used by people in Benin as tool for many activities related to their livelihood. The factors driving fire prevalence in Benin have been described by many authors (Hough, 1993; Thamm, 2008) through social investigation. The following activities are the mainly often reported.

(a) Fires for agricultural land clearing

Clearing natural vegetation with fire for agricultural use is as common in Benin (FAO, 2007b) as in most countries in Africa (Crutzen and Andreae, 1990). That is related to the slash-and-burn system used by most of farmers. Benin is a poor country and the farmers do not have adequate machines to clear the vegetation for new agricultural areas. Fire serves therefore to shifting cultivation (Figure 1.1), to convert forests to agricultural and pastoral lands, to remove dry vegetation in order to promote agricultural productivity and to combusted agricultural waste (Crutzen and Andreae, 1990). They found many advantages from that practice. First, they think that is the unique way to clear. Secondly, the ashes from the burning are supposed to act as fertilizer. Finally, it is a way to fight against plant parasites.

Figure 1.1: Fire in shifting agriculture (Source: our survey)

In the southern part of the country, those fires are started between February and April, late in the dry season till the first rains occurs. In the Sudanian and sudo-Sahelian region, the vegetation is burnt until May.

(b) Fires supporting hunting and gathering

Hunting is mainly practiced during the dry season and is the primary reason for bush fires that are often out of control and that cause extensive property and sometimes human damage each year. Fires for hunting are used in central and northern Benin. Small hunting fires are lit early in the dry season in December by groups of young men hunting small animals such as rodents. That hunting can become a very well organized and large structure at village or groups of villages scale. The hunting are mostly organized during the dry season from January to May (DGFRN, 2008).

Figure 1.2: Early fire (Source : our survey)

(c) Fires for gathering wild honey

The gathering of wild honey is also an important activity of the dry season in the forests and savannas. The torches of fire used in the night to destroy the hives of bees are abandoned carelessly in the vegetation. Those torches of fire generate uncontrolled bush fires (DGFRN, 2008).

(d) Fires use by pastoralists

These fires occur mainly in dry season, affecting the entire country. They are started by shepherds on transhumance to stimulate the natural regeneration of fresh and tender forage (Hough, 1993). The pastoral fires are uncontrolled and are sometimes the source of conflict between pastoralists and local farmers. They are probably the main cause of burning of protected forests. Large areas of savanna, forests and fallows are affected every dry season by these fires.

(e) Protective fires

They are lit by plantation owners and farmer very early at the beginning of the dry season and used to wipe away any flammable natural vegetation that could become fuel for accidental fire (DGFRN, 2008). Many infrastructures including houses and lofts are protected that way. This applies also to the burning around private plantations of palm, teak, and fruit orchards.

(f) Fire to renew leaves of *Vitex doniana*

This type of fire is mainly lit by rural women (DGFRN, 2008). In Benin, young leaves of *Vitex doniana* are eaten as vegetable and are a source of outcome for rural women. To stimulate the renewal of *Vitex doniana* leaves, women set fire to fallow land. They pass these burned areas afterwards to harvest the young leaves. This kind of fire is mostly used in the departments of Atlantique and Zou. The burning is uncontrolled and can affect large areas.

(g) Controlled fires for management inside National Parks

Preventive fires are used by forest officers to protected Parks, plantations and forests against late fires. Especially at the national parks Pendjari and W, fires are also used for pasture regeneration for games and for easing sightseeing for tourists. The burnings are controlled by them and are mostly early(DGFRN, 2008).

(h) Other factors causing bush fires

Other factors playing a role in fire generating have been reported. Those includes, fires started by villagers in Benin to increase the supply of charcoal, fires used to take revenge on the national parks, grudge and arson fires, fire generated by children at play, fires started by burning cigarette butts, Religious and ceremonial bush burnings, escaped prescribed fires etc.

1.3 Present fire management policies

In Benin different offices are involved in the management of bushfires. Those offices are Ministries and other organizations. This section provides an overview of their responsibilities and roles.

1.3.1 Institutions, responsibilities and roles

(a) Ministries

Three ministries are directly responsible for the management of bushfires in Benin. The Ministry of Environment and Nature Protection (MEPN) and the Ministry of Agriculture, Livestock and Fisheries (MAEP) have particular technical skills and the Ministry of Decentralization, Local Governance, Administration and Planning (MDGLAAT) is responsible for coordination and mobilization. They play their respective roles through their various departments :

- the General Direction of Forestry and Natural Resources (DGFRN) and the Forest Inspectorate (IF) for the Ministry of Environment and Nature Protection (MEPN)
- the Regional Centres for Agricultural Promotion (CERPA) for the Ministry of Agriculture, Livestock and Fisheries (MAEP)
- the prefectures and municipalities for Ministry of Decentralization, Local Governance, Administration and Planning (MDGLAAT)

Roles and responsibilities of these departments in the management of bushfires are not explicitly defined in their respective missions and powers (Art. 36, Decree no 2006-460 of 07 September 2006, the responsibilities, organization and functioning of the MEPN).

(b) Units of forest of The departmental office of environment and nature protection (DDEPN)

Departmental office of environment and nature protection (DDEPN) is in charge of fire management activities via the Forest Inspectorate. The Forest Inspectorate has the mandate to monitor, support and advice municipalities' activities related to fire management. It should organize information sessions, education and awareness of public on fire burning preparedness, early prescribed fire management and fight against late and uncontrolled fires. Despite these attributed roles, no continuous regular activities in this direction have been recorded so far. The few sporadic fire management activities recorded are those realized by offices such as National Office of Wood (ONAB) and the National Center of Management of Wildlife Reserves (CENAGREF) or those in the framework of regional or local forestry development programmes such as Fuel Wood Project-Phase II (PBF II), the Program Management of Forests and Countryside (PGFTR), the PAMF, the Program of Natural Resources Conservation and Management (ProCGRN). The extent of activity areas and period of those programmes and centres are then restricted. It is also noticed that controlled fires management measures implemented during projects, though relevant and feasible by local actors and forest services, are no more operational beyond the end of the projects (DGFRN, 2008). In the past the strategy of protecting forest resources against fire involved the whole national forest areas, plantations and protected areas. Thus, controlled fires were lit early in the protected area after informing the local population. Until 1995, the State provide financial resources to the Forest Services to achieve annual perimeter firewalls and the controlled early burning around plantations lands and forest reserves. These financial supports for active prevention of bushfires are losing incentive except in those protected areas still under the management of projects, programmes and centres or offices of the Forest Service. Despite the existence of a variety of projects and programs and players in sustainable management of natural resources in the forestry sector involved in the control of bush fires, no initiative of strategic alignment or creation of synergy on the controlled management of bush fires has been observed. Each project and program has its own strategy.

(c) Agricultural Advisory Services of the Regional Center of Agricultural Promotion (CeRPA)

Agricultural Ministry and its organs are involved in fire management issues because first, biomass burning have causes in agricultural activities and second fires damages often affect agriculture production and stocks. Apart from routine information arousal recalled by agents of the CeRPA, the CeRPA work in close partnership with local radios duly selected to disseminate news and information programs and awareness of preventive measures, targeting rural people. Similarly, officers in the field taking advantage of meetings with farmers' organizations to pass messages to alert members against bushfires. However these activities are no more formal and the information spread are not regularly updated or not based on recent scientific findings. In this case, the technical messages issued probably underwent many alterations.

(d) Local authorities

Departments of Prefectures and municipalities are institutions of MDGLAAT involved in the management of bushfires, as structures of territorial administration responsible for public safety. They are supposed to organize and lead fire prevention, control and rehabilitation activities on their territories.

(e) Prefectures Departments

Prefectures include the department of country planning (PSAT) which is mandated for fire management. Currently, at the prefecture, the fire management is a prerogative of the Department of regional development (PSAT). Prefecture is the chair of the Departmental Committee for Civil Protection and is therefore responsible of coordination at district level of all activities related to emergency assistance to victims of fires related disaster.

(f) The Town council

Decentralization in force in Benin gives roles and responsibilities to local authorities in various fields, including management of natural resources. Hence, local authorities are entitled to the following attributions:

- participation in forest prior diagnosis;
- development of resource management in the framework of communal development plans;
- acting as main project contractor in the forestry sector including protected forest;
- supervision of the implementation structures of exploitation and management
- Monitoring compliance to planning criteria;
- mobilization of fundings;
- ensuring the reallocation of outcomes from exploitation of natural resources;
- participation to the protection of natural resources.

Article 108 of the Law No. 97-029 on the organization of Municipalities in the Republic of Benin stipulates that municipalities exercise their power in accordance with the sectoral strategies, regulations and national standards in force. If necessary they may ask for the technical assistance services of the State. The municipality can create its own technical offices. In addition, in achieving his activities, and under his command authority, it may delegate grant, lease, subcontract or contract. Actually local authorities respond almost only to property or humans damages caused by fires and they request sometimes assistance of forest officers, the police and agricultural officers. Municipalities occasionally get assistance from projects and programs to support local development of bushfires management initiatives. One successful case is the joint project of IMPETUS with GTZ/ProPGTRN in Boukoumbé (Atacora)

1.3.2 Other public institutions

These are courts of first instance and gendameries, which are not directly involved in the management of bushfires and fires, but downstream, conflicts and disputes arising.

(a) General Court

General court hears only two cases of criminal fire:

- case of arson where the perpetrator commits the act deliberately. Arson is a crime and depending on the importance of damages, punishment varies from imprisonment for a fixed period to forced labor for life.
- case of unwanted fires when the act is not premeditated. In this case the perpetrator is fined 6,000 FCFA to 36,000 FCFA and may be kept to jail for 8 days without prejudice to the damages to the owner.

Records of fire due to bushfire are transmitted through the gendarmerie and the Forest Inspectorate. The management of disputes depends on the nature of the fire. In the case of unintentional fire, officials of Water and Forestry send the records to the general court for review and forward it to the police court (responsible for fines). Then the authors are heard and punished. The amount of the fine is determined after evaluation of damages by the Forest Inspectorate. For cases of arson, records are forwarded to the prosecution and the accused is heard by the criminal court. The penalties provided for in the Penal Code in relation to bush fires are often not a satisfactory solution for the victims. Indeed, the fines are often small compared to the damage caused due to changing costs and prices. And it happens as often as the perpetrators of these acts can not afford to pay.

(b) Gendarmerie

Gendarmerie represents the police in rural areas and support implementation of forestry legislation. Mounted Brigades are the direct interface between local conflicting parties on fire prejudices and the court. Some conflicts can be solved locally by the gendarmerie.

1.3.3 Socio-professional organizations

They are grouped into three categories according to the sector: agricultural socio-professional organizations (IPOs), community organizations for natural resource management and socio-professional organizations in the forestry sector. They are often important negotiating partners for the spreading and the downscaling of information, mobilization and awareness to their members. They need more support from the government. Their current knowledge in this area is limited to awareness sessions held in the past by the CERPA in collaboration with the forest on the one hand, and radio broadcasts that address issues of fire management. The existence of community organizations in managing natural resources is relatively new and has no legal existence.

1.3.4 CBOs / village management of natural resources

Community based organizations (CBOs) are nonprofit groups that work at a local level to improve life for residents. In general, there are two types: village committees to fight against late bush fires and participatory management structures of protected forests and plantations. Many community based organization are created in the context of natural resource management programme as local partners in participatory fire management activities. Unfortunately they duration is no longer than the one of the program.

1.3.5 Non-governmental organizations (NGOs)

National NGOs working in the field of Environment Protection and Management of Natural Resources are quite numerous but few lead actually fire management activities. In general, they get fundings from external sponsors to solve wildfire issues. They mainly deal with communication, public awareness raising but they are often not technical competent in prevention and fight against fires. Some of them provide their service for projects PGRN, PGTRN, PAVICO, PGFTR and ProCGRN. Yet there are some Non governmental Organizations such as the German Technical Cooperation organization (GTZ) which are also backing standalone fire management projects.

1.3.6 Legal framework

The Act 93-009 of 2 July 1993 on the regime of forests in the Republic of Benin and its decree 96-271 of 2 July 1996 on the management of bushfires define the legal framework on vegetation fire issues. Article 56: bushfires and forest fires are those fires which destroy the vegetation, regardless of their size and their origin. Article 57: Fire and uncontrolled or late bush fires are prohibited. Their practice is punishable under Articles 94 and following of Act 93-009 of 2 July 1993 on the regime of forests in the Republic of Benin and its decree 96-271 of 2 July 1996 on the management of bushfires. However, the burnings may be permitted. The terms of these burnings are specified by decree taken by the Council of Ministers. The legislation in Benin allows only controlled fires in the vegetation. Any other fires are banned penalties are provided therefore. Every year the government officially precise which periods should be fire seasons for each department. Unfortunately, it still lacks appropriate means to monitor and assess the compliance to this statement.

1.3.7 Management policies

Before the colonial years, wildland fire control in Benin as in other countries in the West-Africa was governed by check and balances. During the colonial period a definition and application of another approach of fire management are adopted, prohibition and prescribed fires are then born. This approach lasts until recently.

1.3.8 Prescribed early fire

Prescribed times of early fires setting in Benin:

- Department of Atacora-Donga: from 1st December to 30th December;
- Department of Borgou-Alibori: from 1st December to 30th December;
- Department of Zou-Collines: from 15th December to 30th December;
- Department of Ouémé Plateau: from 15th December to 30th December;
- Department of the Atlantic coast: from 15th December to 30th December;
- Department of Mono-Couffo: from 15th December to 30th December;

It is important to note that these dates are fixed since 1993, although changes in the fire regime and the ecosystem are likely expected to occurs in time. It would be more useful to have the possibility to improve the statement every year and to assess the results.

1.3.9 Fire suppression

Fire suppression can be achieved by creating fire extinction facilities. In Benin, fire suppression resources are limited and not adequate for prevention of wildfire occurring in rural areas. There is so far no way to prevent people in remote area from setting fire in natural areas. What is more, the fire suppression offices only have mandate to deal with fire in urban areas.

1.3.10 Community participation

Ampadu-Agyei (1988) noticed that a complete prohibition of bushfire, especially in the rural areas would be impossible because the "burning culture" belongs to the traditional way of life of the local people. He recommended some policies to prevent bushfires. Education and awareness of the population at every level were central points of his recommendations Forest management officers in Benin have done great efforts regarding community participation in their struggle against wildland fire. Their approach includes :

- education and training of local farmers;
- awareness raising among people through posters, warning signs, broadcasting, grassroots fire education;
- trainings of stakeholders at all levels for the proper use of fire as a management tools

However, these activities were not able to completely stop fires.

In view of what comes before, many institutions and civil society organizations are involved in fire management issues. Public services mandated to manage bushfires are, however facing various challenges to properly do their job. A clear and rigorous strategy of fire management is needed. The various activities in the field undertaken by different actors should be in a concerted and coordinated framework. But a sustainable joint management of fire by all those organization would be effective only if they are working on uniform information sharing approach. That means there should be basic and reliable scientific information on fire situation of the country, which they could base their collaboration on. Capacity building in participatory bush fire management planning is also an important factors that should be reinforced. Although their focus on information - communication and awareness on fire danger and fire protection using the diversity of radios is an opportunity to effectively reach communities with appropriate messages, they should provide more technical management input. The management action advised by public officials should go along with well-organized country wide relevant fire management, detection and control technical activities, such as organizing synchronized early burning, installation of fire-breaks, management of fuel load. A definitive requirement is adequate infrastructures and equipment resources for fire prediction, fire monitoring, fire stopping and for assessment of fire damages and results of management actions. Those materials or settings are inadequate or inexistent. Funds raising should also be effective. Mobilization of financial resources at appropriate time should be assured. Monitoring and evaluation of bushfires is not exercised with regularity and reliability by the agents of public services. On one hand that is due to lack of interest at each level of decision-making process. On the other it requires special skills that the officers do not have. There should be a way to monitor the success of those programs.

1.4 Problems: need of an objective, improved and low-cost vegetation fire management strategies

The traditional fire management is not the best to deal with the existing culture of burning. Considering that fires to large extent shape savannas vegetation, this fire-affected ecosystems need fire to induce regeneration and to maintain and enhance biodiversity(FAO, 2007b). In addition, fire is required to enhance the carrying capacity of pastoral systems. Taking into account this high dependence of savannas to fire, many changes are to be expected from the ecology of these ecosystems under continuous uncontrolled vegetation fire. The changes in the vegetation structure will affect the overall carbon cycle and impacts regional climate. These change can lead to many consequences including the advance of desertification. Considering the high rates of population growth, human the pressure on natural vegetation will increase. It is therefore necessary to find a way to evaluate scale of fires impacts and take a sustainable prevention, preparedness, suppression and rehabilitation action.

Even though, although there are laws which aimed to regulate the fire use, the check of compliance to those laws is not effective because the infrastructure are not installed to monitor burned areas. For the same reason, there is no way to characterize the regime of fire. A rigorous assessment of action is also not possible. A way to quantify the impact, trends and scale of the threat and effectiveness of action should be found. That could only be done through collection of information at country level in a systematic way (FAO, 2007a). The current fire management strategies also have to be improved through rigorous scientific analysis.

Moreover, as environmental disturbance by fire is a global issue, a rational setting of fire monitoring will facilitate and promote the exchange of fire information among various countries and to improve fire prevention strategies (JRC-EU, 2005). If a good strategy is found a reduction of the impact of fire on environment could be expected. This is only conceivable through establishment of advanced detection and monitoring systems. Options for fire management varies from one location to another. An effective decision making process is also strongly related to expert knowledge. Therefore a mere GIS solution for fire management, where a fixed solution is proposed will not be very useful. In other words, there is no explicit solution to fire management issue. It is a semi-structured problem which can only be addressed by Spatial Decision Support System.

Within this PhD we regionalized a SDSS and use it to investigate the spatial and temporal distribution and the regime of vegetation fire in Benin.

1.5 Research objectives and questions

The overall research objective is a theoretical concept and the realization of SDSS for optimization of fire management in Benin. The research goals can be subdivided as follows:

1. to embed the work in a theoretical concept of fire ecology and modern research on SDSS
2. to define the work flow for vegetation burning assessment in collaboration with responsible decision makers in Benin
3. to investigate the degree of the minimum complexity which is needed to find appropriate solutions and the maximum complexity which the user can handle, maintain and extend.
4. to create the SDSS for fire management FIMAT using MODIS datasets
5. to formulate and investigate the interrelation between the different sources of information
6. to integrate input data in the SDSS FIMAT
7. to relate bushfire pattern and frequencies to land cover type.
8. to relate bushfire pattern and frequencies to rainfall distribution.
9. to find suitable ways to systematically check the compliance to the law statement.
10. to use FIMAT in an adaptive management process to improve management practices and technologies.

The following questions are therefore necessary to address:

- What environmental and socio-economic processes underlay bush fire occurrence.
- What are the conceptual and methodological demands for the development of an user-friendly SDSS for Bush Fire?
- How can the existing information be downloaded and integrated in a SDSS for Bush Fire?
- What are the seasonal and interannual dynamics of bush fires?
- Is burning pattern related to land use type?
- Do the rainfall characteristics have any influence on fire dynamics?
- What are the requirements for the development of an effective fire monitoring and decision support system?
- How the information derived from the use of the developed SDSS can support decision of fire management?

This should be done through investigation based on the subsequent hypothesis.

Research hypothesis

	Hypothesis	Methods	Required data	References
Climatic factors	Spatial and temporal distribution of fire follow a regular pattern	Correspondence analysis	MODIS burnt areas product (available online)	
	Variability in season and rainfall amount affects the fire occurrence pattern	Charting fire frequency against rainfall regime. Relate total rainfall amount to total burning area for each year	Rainfall distribution (SMN Benin database) MODIS burnt areas product (available online)	FAO (2007b)
Policy	Early fires reduce the frequency of fire in one season	Relating the first occurrence date to the frequency of burning	MODIS burnt areas product (available online)	Well know assumption (basis of most management policy). (Aubréville, 1947)

	Hypothesis	Methods	Required data	References
	Early burnt areas sizes are smaller than late burnt areas sizes	Calculating and comparing the descriptive statistics of burned area for both moments.	MODIS burnt areas product (available online)	
	Fires are lit according to the prescribed fire period	Comparing burning event dates to the prescribed one using the histogram of these dates	MODIS burnt areas product (available online)	Fire management policy and regulation in use in Benin
	The frequency of fires in protected areas depends on the existence of pathway in those areas	Relating fire frequency to distance to layer of pathway.	MODIS burnt areas product (available online) Roads in Benin (shape file available)	Suggested by the observations
Land cover	The frequency of fire depends on land cover type	Relating the vegetation composition to the frequency of burning (Khi square analysis)	MODIS burnt areas product (available online) ESA GlobCover 2004-2006 product (online)	
	The earliness of fire depends on the land cover type	Relating the burning date to the land cover (Khi square analysis)	MODIS burnt areas product (available online) Global Cover Image (online)	

Chapter 2

Location of Benin in savanna area and fire incidence

2.1 Location

The Republic of Benin is located on West coast of Africa within longitude 0.7°and 3.8°and latitude 6.2°and 12.5°(Figure 2.1). The total land area is 112 620 Km^2. Benin bounders Niger and Burkina-faso on North, Togo on West and Nigeria on the East.

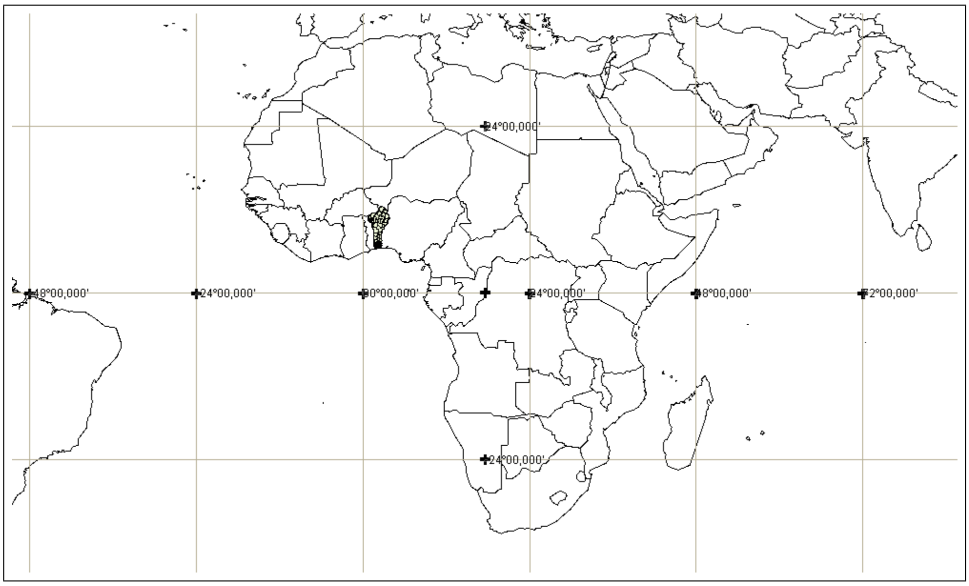


Figure 2.1: Study area: Benin countrywide (data source :ESRI)

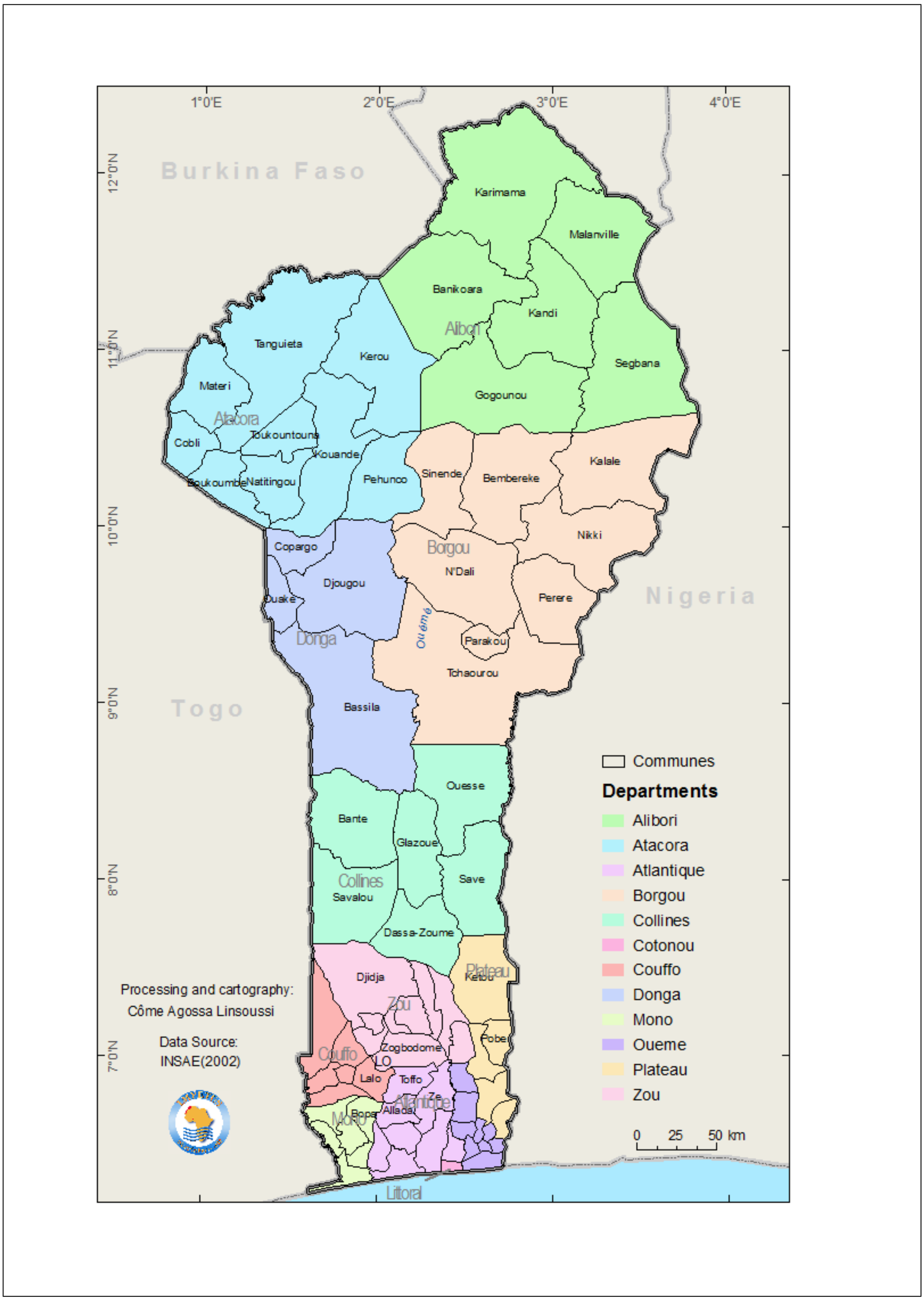


Figure 2.2: Study area: Benin countrywide (Data Source : INSAE (2003))

2.2 Biophysical environment

Fire is tightly linked to the environment parameters. Pattern of vegetation burning in any area is shaped by the biophysical environment characteristics of that area. In order to evaluate the fire context in Benin, it is important to have background information on the biophysical environment of Benin. In this subsection, focus is on the biophysical environmental settings of Benin.

2.2.1 Climate

Climate in Benin is tropical, varying along the latitude. Mainly three climatic regions are distinguished in Benin: the southern climate zone, the central climate zone and the northern climate zone (Adam and Boko, 1993).

The southern Guinean zone has an equatorial type of climate with a bi-modal rainfall distribution between the coast and 7°30N. The principal rainy season occurs between mid-March and mid-July; the shorter dry season lasts to mid-September; the shorter rainy season lasts to mid-November; and the main dry season lasts until the rains begin again in March. The amount of rain, 1000 mm in the west, increases toward the east (1485 mm)(Le Barbé et al., 2002). Temperatures are fairly constant, varying between about 22°and 34°C, and the relative humidity is often high between 60% and 90% (World Meteorological Organization, 1996).

The northern Sudanian dry, semi-arid climatic zone located between latitudes 10°30'N and 12°N is uni-modal and characterized by one dry season followed by one rainy season. The rainy season lasts from May to September, with most of the rainfall occurring in August. Rainfall amounts to about 1200 mm a year in the Atakora Mountains and in central Benin; further north it diminishes to about 800 mm. In the dry season the harmattan, a hot, dry wind, blows from the northeast from December to March. The effects of this wind are very strong in the north. Average temperatures is 27°C, but the its range varies considerably from day to night. In March, the hottest month, diurnal temperatures may rise to 43°C.

The center Sudano-guinean region is characterzed by transitional climate. In this region the rainy seasons tend to merge.

2.2.2 Geology and soils

Soils in Benin are distributed according to the following general pattern: in the south, ferallitic and hydromorophic soil are dominant; the central part is mainly characterized by Acrisols and Lixisols; shallow soils (lithosols and sols peu evolués lithiques)are more frequent in the mountains of Atakora. “Sol ferrigineux tropicaux lessivés hydromorphes” are spread in the national park of Pendjari (Figure 2.3)(IMPETUS Atlas Benin, 2008).

2.2.3 Relief

The following five natural regions are found in Benin (Britannica, 2010): coastal region, barre country, plateaux, Atakora Mountains and Niger plains. The coastal

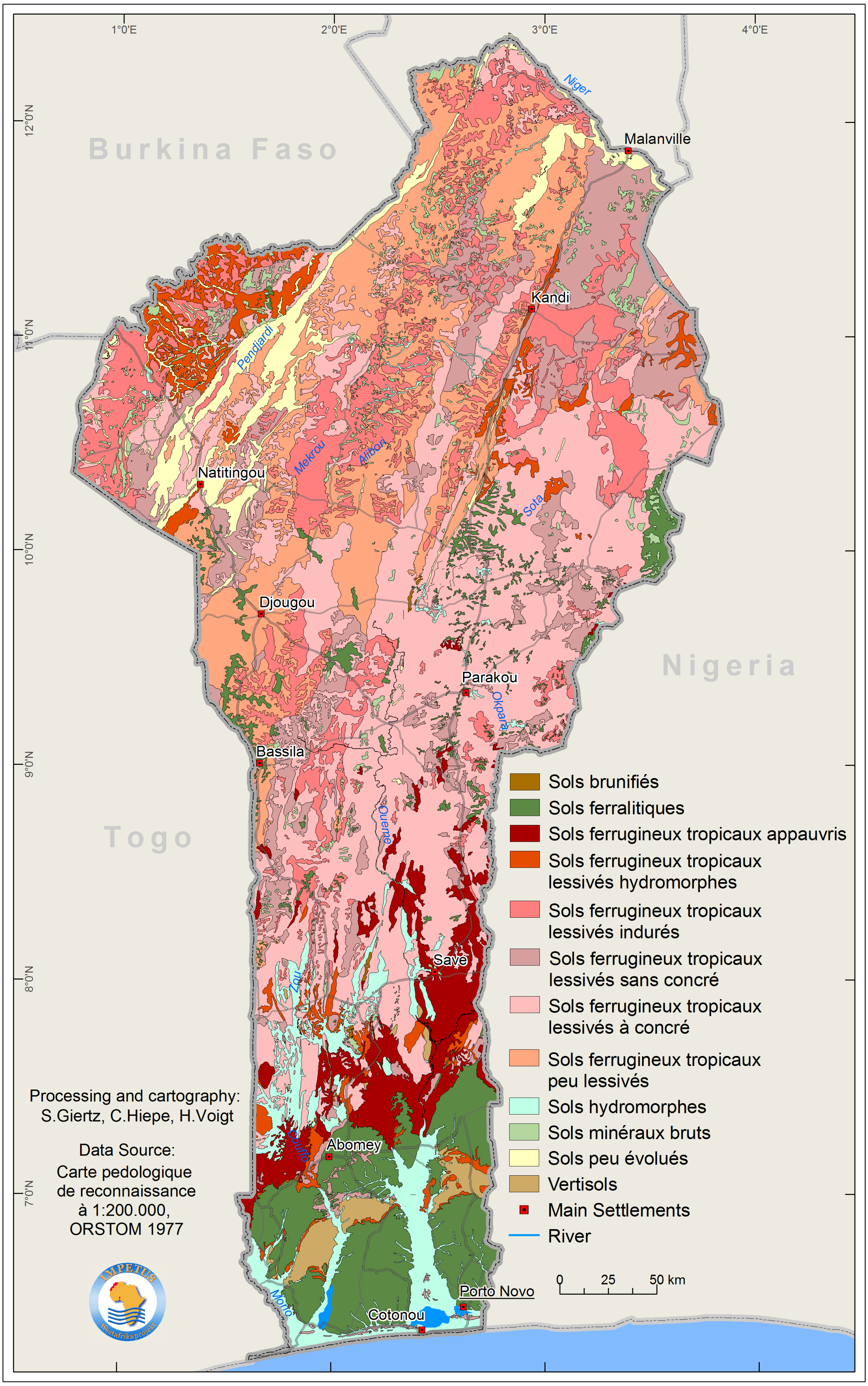


Figure 2.3: Soils in Benin (Source : IMPETUS ATLAS (2002))

region is low, flat and sandy, dotted with marshes and lagoons. Many lagoons in western part have become marshes because of silting, and wider in the east.

Behind the coastal region extends the “terre de barre” –the word being a French adaptation of the Portuguese word barro ("clay"). A fertile plateau, the barre region contains the Lama Marsh, a vast swampy area stretching from Abomey to Allada. The landscape is generally flat, although occasional hills occur, rising to about 400 meters.

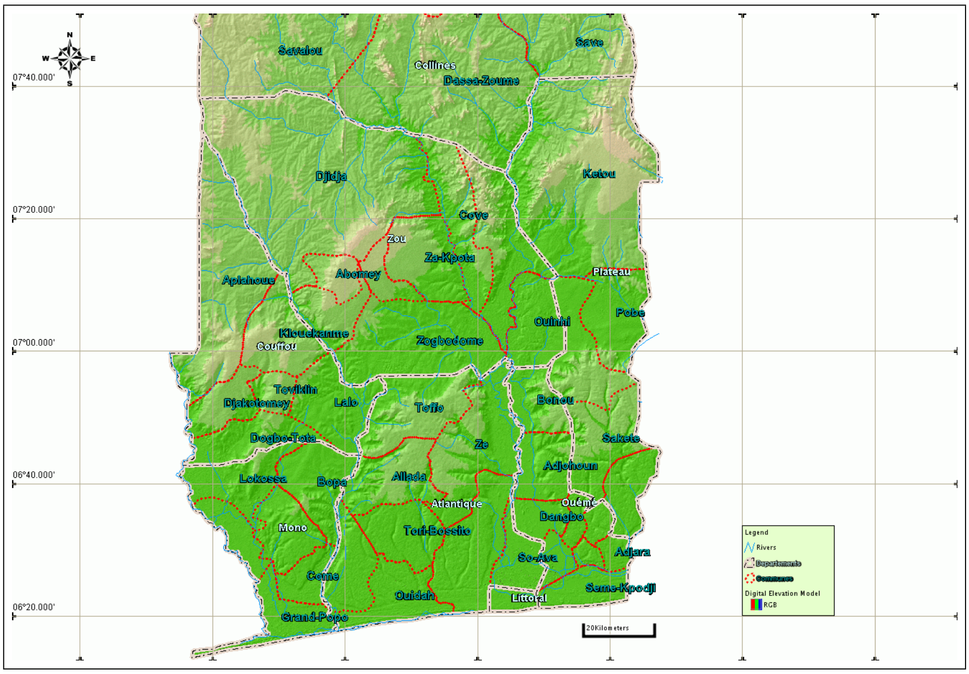


Figure 2.4: Relief South Benin (Source : IMPETUS ATLAS (2002))

The four Benin plateau are found in the environs of Abomey, Kétou, Aplahoué and Zagnanado. The plateaus consist of clays on a crystalline base. The Abomey, Aplahoué, and Zagnanado plateaus are from 90 to 230 meters high, and the Kétou plateau is up to 150 meters in height.2.4

The Atakora Mountains, in the northwest of the country, are a continuation of the Togo Mountains. Spreading from southwest to northeast and reaching an altitude of 641 meters at their highest point, they consist of a highly metamorphosed quartzite interior.

The Niger plains, in the northeast of Benin, slope down to the Niger River valley. They are composed by the clayey sandstones.

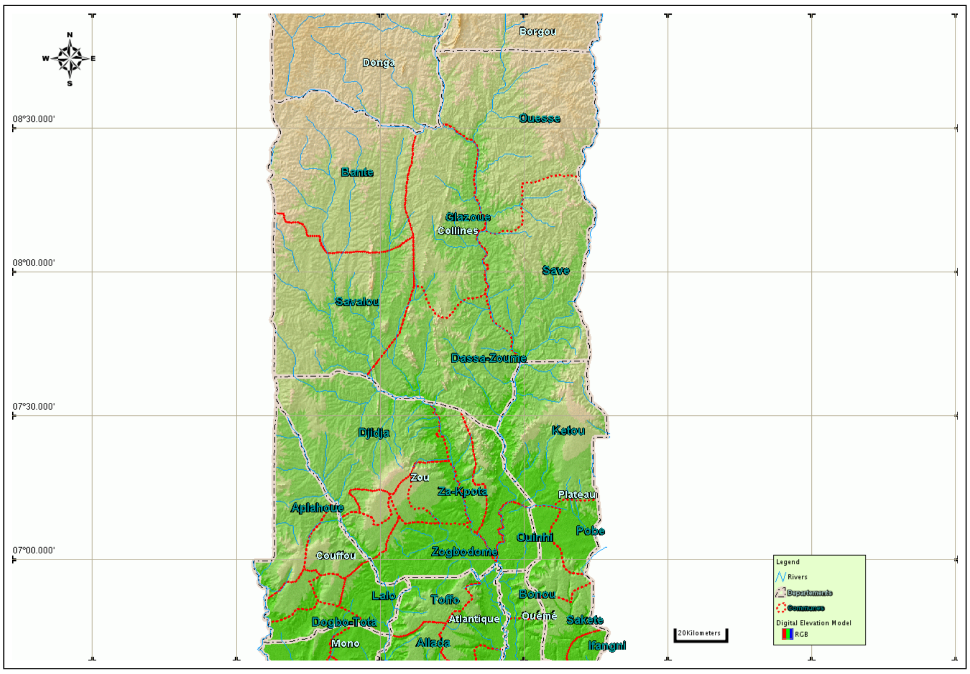


Figure 2.5: Relief Center Benin (Source : IMPETUS ATLAS (2002))

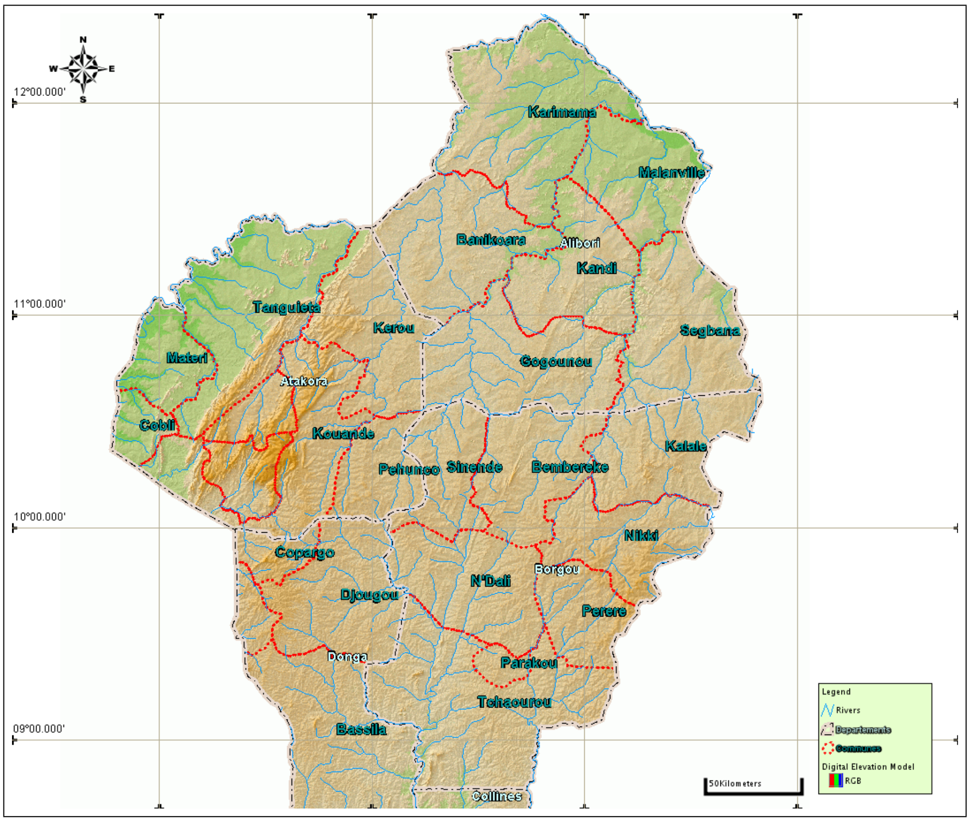


Figure 2.6: Relief North Benin (data source :IMPETUS Atlas Benin (2008))

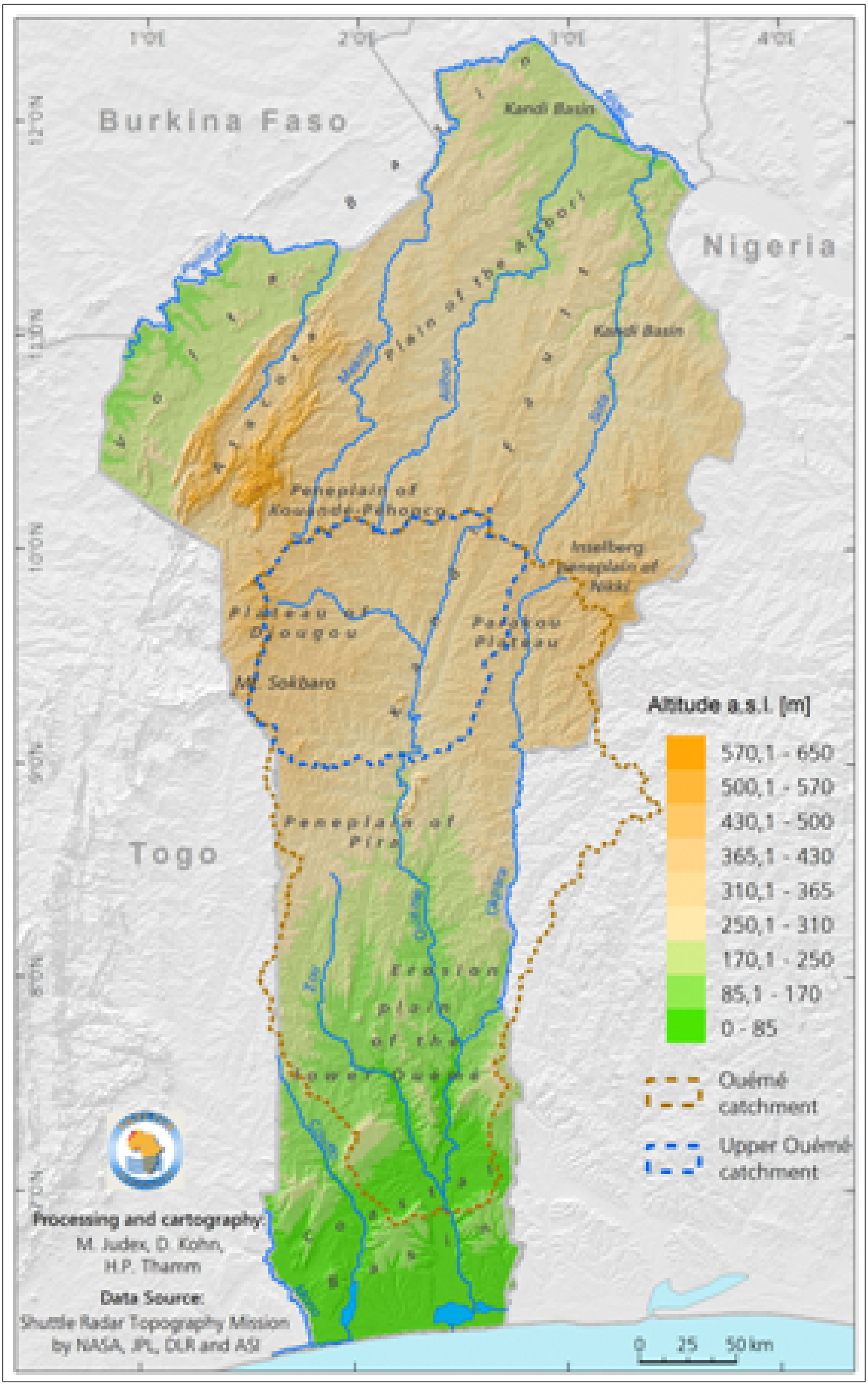


Figure 2.7: Topography and main rivers system of Benin (data source :IMPETUS Atlas Benin (2008))

2.2.4 Hydrology

Mono, Couffo, Oueme and Niger with its tributaries Mékrou, Alibori, and Sota are the main rivers of Benin (Figure 2.7). The river Mono forms the border between Togo and Benin near the coast. The Couffo flows southward from the Benin plateaus to drain into the coastal lagoons at Ahémé. The Ouémé rises in the Atakora Mountains and flows southward for about 450 km. Near its mouth it divides into two branches, one draining to the east into Porto-Novo Lagoon and the other to the west into Nokoué Lake. The Atakora Mountains form a separator between the Volta and Niger basins.

2.2.5 Vegetation

The Republic of Benin lays in equatorial zone, thus the vegetation should be dominated by rain forest. Due to the Dahomey Gap however, an interruption of the rain Guinean forest occurs at the area of Benin, Togo and Ghana. Savannas and shrublands represent about 50% of the vegetation. Savannas dominate particularly in the north beyond 8°N. Forest-galleries are found along the rivers. Other types of forest found in Benin belongs to the protected area and represent 1436500 ha. The protected areas include also two national parks (843 000 ha): Pendjari and W and the wildlife reserve (420 000ha). Plantations represent about 2% of the country area consisting of teak, palm trees in the South, cashew trees in the centre and in the North.

Figure 2.8: Savannah:grasslands IMPETUS Atlas Benin (2008)

2.2.6 Fauna

Benin has two national parks with rich biodiversity. In the far North is the "W" National Park (1,938 square miles), extending to Burkina Faso and Niger. The Pendjari National Park (2750 square kilometers) borders Burkina Faso on West. These parks include many tropical mammals such as *Loxodonta africana* (African elephant), *Panthera pardus* (leopard), *Panthera leo* (lion), *Tragelaphus scriptus* (Bushbuck)antelope, monkeys, wild pigs, and Syncerus caffer (African buffalo)(Pendjari National Park, 2008). See a detailed list in Appendix. There are many species of reptiles such as crocodiles, pythons and puff adders. Birds include guinea fowl, wild duck, and partridge.

2.3 Administrative organization

Benin Republic is divided into 12 administrative departments: Alibori, Atacora, Atlantique, Borgou, Collines, Couffo, Donga, Littoral, Mono, Ouémé, Plateau, and Zou. At lower scale, the country consists of 77 municipalities (Communes). Each municipality is subdivided into divisions managed by councils of districts appointed from municipal. Villages and city districts organize social life and production activities. They are also administered by councils of village or neighborhood and headed by chiefs of villages or city districts (Figure 2.2).

2.4 Socioeconomics and demographic features

2.4.1 Demography, settlements and land-use system

According to the General Population and Habit Census in 2002, (INSAE, 2004) population of Benin was 6.8 million with an annual growth rate of 3.2%. Based on this figures the present population of the country is estimated to 8.7 million (INSAE, 2004)), 62.5% is rural. Population is unevenly distributed. The southern provinces make up 12% of the total area but are inhabited by more than 64% of the total population with the population density ranging between 224 to 8419 inhabitants /km^2, while in the north, the density ranges between 20 and 38 inhabitants / km^2 on average. In North, the aspect of the countryside changes as savanna vegetation increases and the population diminishes. Some areas are uninhabited, with only exception of Fulani nomads. Villages are quite scattered (Figure 2.10). Agriculture represents the main socio-economic activity of about 70% of the workforce and contributes to 38% of the GDP. The agricultural activities are represented by small scale traditional slash-and-burn system. The cultivation of subsistence crops, such as corn (maize), cassava, and yams, is extensive. The barre region and the Benin plateaus are covered by oil palms, which form the cash crop, as well as with subsistence crops. Cotton, the main cash crop, is cultivated in the northern and central regions. It contributed in 2001 to 81% of exports in Benin, while share of oil palm, cashew, pineapple were approximately 7%. Yam is a major staple food for some areas in central and northern Benin. Yam is usually cultivated on new deforested areas. Estimated 50,000 ha of vegetation are destroyed annually by fire

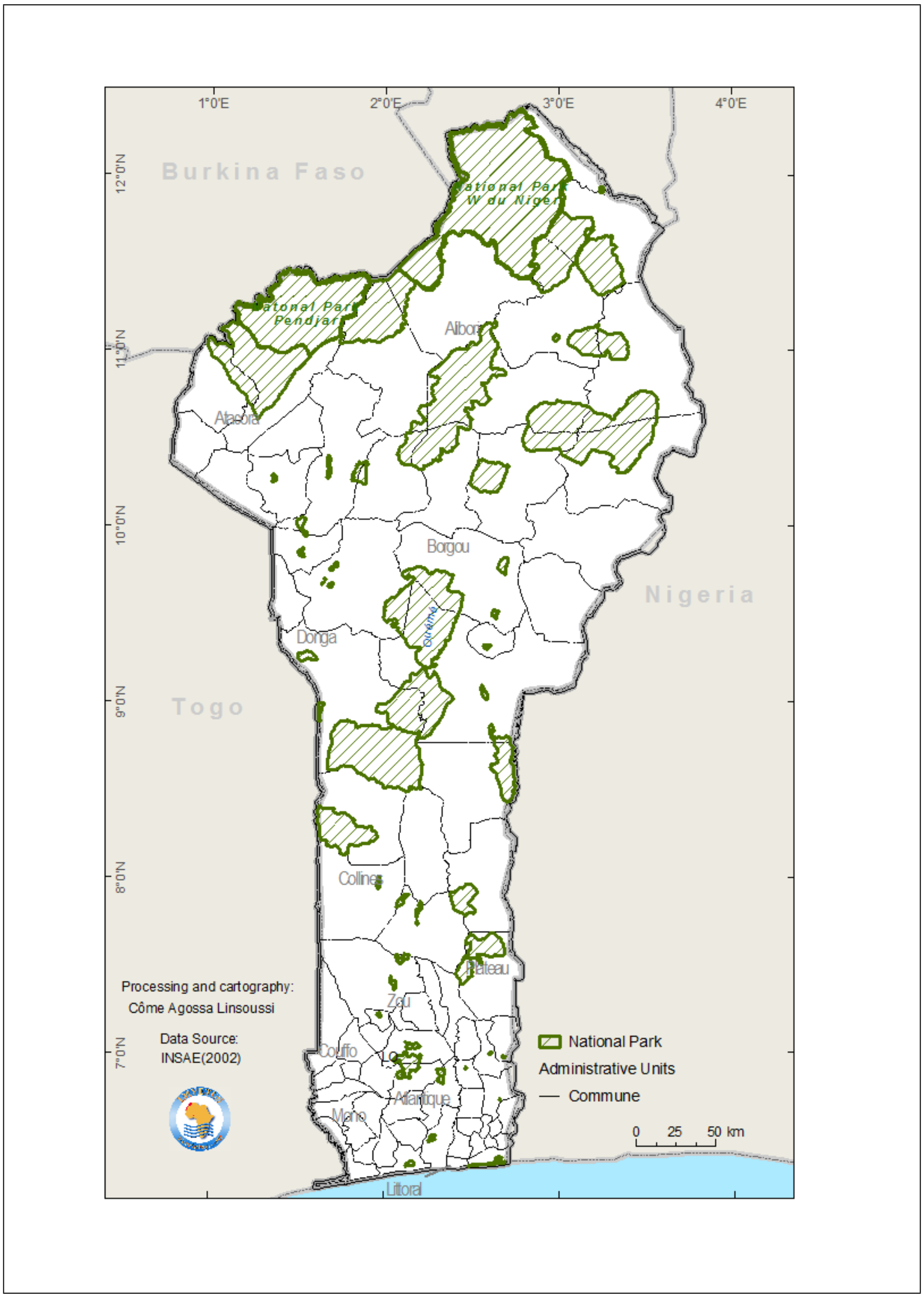


Figure 2.9: Protected areas (Data Source : CENATEL)

for new agricultural land reclamation in the northern region of Benin. Livestock is the second major socio-economic activity of the rural population.

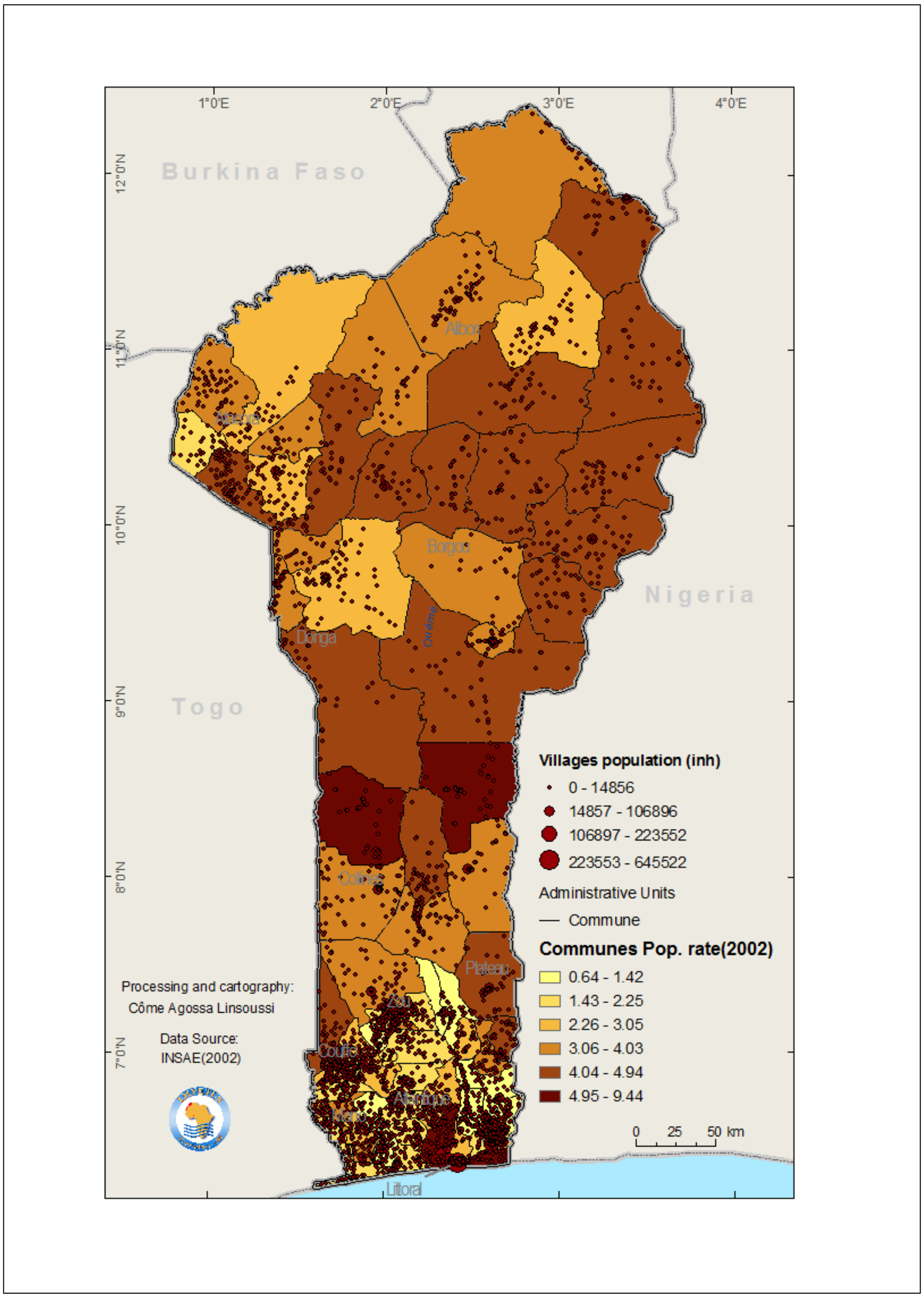


Figure 2.10: Population 2002 Benin (INSAE, 2003)

Chapter 3

Theories on fire ecology and (state-of-art) methods in spatial decision support (SDSS)for bush fire management

3.1 Introduction

Many theories explains the interrelations between fire and other components of the habitat where it occurs. An insight into those theories is useful to understand vegetation fire issues and existing efforts to manage these issues. It is also necessary to know definitions of some key terms used throughout this document. In this section, we present some theories on fire ecology, decision support system. We also present an overview of available data and methods used to support fire management activities.

3.2 Fire ecology

Fire is a natural process, integral to the function of many ecosystems. Fire ecology is the study of how and by what processes fire behavior and ecosystem effects are linked (Cochrane, 2009). This includes the relationships between fire, living organisms, and the physical environment. Fire's existence depends on a local conjunction of heat, fuel, and oxygen. Fire behavior is a larger scale expression of weather, terrain, and fuel characteristics. By extension, fire regimes are the long-term regional integration of fire's effects within the context of a given climatology, landform, and vegetation. The modification of of any aspect of these relationships will cause an associated ecosystem to adjust its composition, structure,or function to compensate. Likewise, any nonfire-related changes in the ecosystem attributes will alter the fire environment and lead to new fire regimes. The effects of a fire (termed fire effects) depend on the intensity, duration, and extent of a fire, as well as the time of year (season) in which it occurs and the amount of time since previous fire (s) (frequency). Whether the effects of a fire are seen as beneficial or destructive depends upon society's of view and changes with the passage of time since the fire's occurrence. Many ecosystems appear to be totally destroyed by fire but return more vigorously than before, given sufficient time, while others may be radically altered. The main issues addressed in fire ecology are fire dependence, sensitivity and adaptation of plants and animals, fire history, fire regimes, and fire effects on ecosystems. The function of many ecosystems depend on fire as natural process and component of those ecosystems (Cochrane, 2009). The pattern and type of fire in any location is determined by the interrelationships between fire and climate, vegetation and topography, and soil. Climate affects vegetation by shaping the kind of vegetation observable. The type of vegetation in any area depends on the available rainfall and the temperature. Wet and hot weather leads to tropical rain forest while savannas are developed under regular yearly dry seasons (Bond and van Wilgen, 1996). Decision makers can be help in their decision making processes by better understanding fire ecology. That can improve the restoration and conservation of fire adapted ecosystems. This section gives a broad overview of the relationship between fire, climate and vegetation. The description focuses mainly on the impacts of individual fires and fire regimes on biota and habitats on a hand and the adaptations and responses of plants and animals to fire on the other.

3.2.1 Climate, vegetation and fire

Climate, vegetation and fire are tightly linked elements of ecosystem.

(a) Climate affects vegetation

The climate plays a key role in shaping the vegetation types observable at a given place ("potential natural vegetation") (Cochrane, 2009). Ecoregions exist in concert with long-term weather patterns. Under a hot and wet weather through most of the year, tropical rainforest may develop. However, if there is a dry period each year, savannas or grassland will be the predominant vegetation type.

(b) Climate affects fire

The prevailing climate at a location determines how likely it is that vegetation will burn - both in the long term, and seasonally. Many climatic factors like rainfall, wind, humidity, temperature condition the occurrence likelihood, the spread speed and the intensity of fire. Fires occurring in a dry, hot and windy weather are hot and intense. Frequent and reliable rainfall keeps the fuels damp. So, fires will occur rarely, if at all. Instead, areas with prolonged seasonal drought are often at increased risk for shorter fire cycles. Where there is sufficient vegetation and fuel load development, and frequent, prolonged dry periods, frequent fires will result. Tropical rainforest can only be burnt during unusually dry periods. Severe drought in Vast areas of rainforest burning in Indonesia and New Guinea have been observed after severe drought in those areas. Lightning is a critical climatic factor in many areas. Fires are started by lighting when they occurred in dry season. Climate also directly affects how likely it is that vegetation will burn - both in the long term, and seasonally. Fires are most likely to occur after a dry period, in hot, windy weather, when humidity is low. These conditions produce hot, intense fires.

Lightning is another critical climatic factor. Local topography can result in formation of large unstable air masses and thunderstorms.

(c) Fire affects vegetation

Fire affects vegetation. Fire can be very damaging to rainforest vegetation because most rainforest plants are poorly adapted to fire. In dense forests, burning is strongly associated with land-cover changes, while in savannas the occurrence of (mostly) early fires does not lead to land-cover change. Fire determines global vegetation patterns by preventing ecosystems from achieving the potential height, biomass and dominant functional types expected under the ambient climate (climate potential). Without fires, most of which are lit by humans wetter savannas can evolve to semi-deciduous forests(Bond et al., 2005) and closed forests would double mostly at the expense of C4 plants but also of C3 shrubs and grasses in cooler climates. Forest plant functional types in burned grassland are restricted to those with resprouting ability to survive recurrent fire events.

(d) Fire affects climate

Heat from fire induce volatilization of gases and they release in the atmosphere. Organic N released during combustion is oxidized to gaseous forms (NO, NH_3)(Prepas et al., 2010). A great amount of green gases such as CO_2 are released to atmosphere durning vegetation ignition and contribute to global warming.

(e) Vegetation affects fire

Difference in vegetation related to gradients of rainfall, productivity and differences in soil types result into different burning regime,different response to fire and different flammability (Prepas et al., 2010).

(f) Vegetation affects climate

Green house including CO_2 produce hot climate. Plants absorb CO_2 and can hence reduce the temperature. The speed of wind is also definitely reduced by presence of trees. Vegetation regulates the rainfall by evaporation and transpiration process.

3.2.2 Effects of fire on soil

Fire heat can create soil layers hydrolphobicity. Long-chain organic compounds are released from overstorey vegetation and migrate downward into the soil according to the temperature gradient. They condense subsurface and the hydrophobic compounds are deposited. Increasing soil organic matter and litter depth induces soil hydrophobicity as well. Hydrophobicity has a direct impact on water infiltration. It results in water repellent subsurface layer generating lateral flow over the impermeable layer. Fires can destroy the regenerative power of the land. The resultant grass failure to grow can lead to desertification.

3.2.3 Effects of fire on plants and animals

Fire affects plants in a variety of different ways depending on the condition of the plants before it occurs. The impact of fire on plants may increase if the plants have been subjected to other disturbances such as drought, disease, insect infestations, overgrazing or combination of these factors. To achieve a better conservation of biodiversity and ensuring healthy ecosystem functioning it is crucial to gain a better understanding of what effect different fires and fire regimes have on biodiversity and ecosystem function. Intense fires can produce enough smoke and ash to cause immediate chemical toxicity. Moreover, mobility and other response mecanisms may fail for local population when fires are extreme and escape routes are blocked. Phyto plankton, zooplankton and benthic macroinvertebrates are more likely to be affected by in situ hydrological and chemical effects of fire. After drought and during harmattan winds bushfires can destroy large areas of standing crops and stored cereals. Fires lead to loss of populations of plants obligate seeder species

3.2.4 Responses of plants to fire and desirable fire impacts on plants and animals

Many plants and animals in fire prone areas present characters that enable fire survival. Savanna plants and animals, by contrast, are well able to tolerate fire.

a) Re-seeding Plants:

   Reseeders are those plants species that regenerate mainly from seedlings. Their seeds are routinely deposited by gravity, wind, rain, or birds. Reseeders are killed by fires, but germinate from dormant seeds;they are restricted to habitats with fire return intervals long enough to reach reproductive maturity.

b) Myrmecochory:propagation by ants

Figure 3.1: *Rhytidoponera metallica* ant holding a seed of *Acacia neurophylla* by the elaiosome during seed transport (modified after Lengyel et al. (2009))

   The collection and dispersal of seeds by ants(Lengyel et al., 2009) is mediated by the presence of a lipid-rich appendage (elaiosome) on the seed (Figure 3.1) that induces a variety of ants to collect the diaspores. When seeds mature or fall onto the ground, these ant species transport them to their nest. After eating the elaiosome, the seed is discarded in nest galleries or outside, in the midden or farther away, where seeds can potentially germinate(Gómez et al., 2005; Gorb and Gorb, 2003).

c) Sprouting ability: sprouting is a means by which many plants recover after fire. Many plants recover from disturbance by regenerating from dormant buds below or above ground(Bellingham and Sparrow, 2000). They can persist in habitats with short fire return intervals because they do not need a long time to reach reproductive maturity. The ability of an individual plant to sprout following a fire is dependent on the location of its dormant buds, the subsurface distribution of reproductive structures, and the depths below the surface from which new shoots can develop. The relationship between the depths of reproduction organs, combined with the depth of lethal temperature penetration, will determine a plants ability to survive and sprout following a fire. Re-sprouting of plants typically occurs when their buds are protected by bark, dense leaf bases, or soil(Columbia, 2008). Savanna species have very high probabilities of resprouting (Lacey et al., 1982).

d) Bark thickness: Bark thickness has influence on how a fire impacts a tree stem. It is species specific, and dependent on various factors including tree diameter and age as well as distance above the ground, site characteristics, and tree health and vigor. Thicker barked trees can often sustain a substantial amount of bark char before cambium damage occurs. Moreover, older, thick-barked trees are often only damaged or killed when the cambium is subjected to complete girdling or when the trees are subjected to subsequent fires. This generally only happens when these trees are subjected to long duration burns such as those that occur during the burn out of logs, deep litter, and duff. Thick bark increase tolerance to most ground fires, even those that burn into the bark. The deeper the fire burns however, the wore likely complete girdling is to occur. Thus, thick-barked trees are more likely to succumb to fire from crown damage than stem damage.

e) Succulent plants: Succulent plants, also known as succulents or fat plants, are plants which retain water and are adapted to the arid conditions of either the soil or the climate in a particular region. Succulent plants store water in their leaves, stems, and also in roots. Geophytes that survive unfavorable periods by dying back to underground storage organs such as tuberous roots, corms, bulbs, and rhizomes, may be regarded as succulents. Some plants are succulent geophytes. The best known succulents are cacti (family: Cactaceae). Succulents are considered to be good fire resistant plants, although no plant is completely fireproof. Succulent plants are fire resistant for a number of reasons:

- succulent leaves do not contain flammable oils or volatile chemicals
- there is a high moisture content in succulent plant tissue

- succulents seem to flourish in high risk fire areas which are often dry and sunny
- succulent plants mainly grow close to the ground.

3.3 Definitions and concepts

3.3.1 Geographic Information System (GIS) Definition

There is no absolutely agreed upon definition of a GIS (deMers, 1997). Dueker and Kjerne (1989) defined Geographic Information System as "a system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth" . After Goodchild and Kemp (1990), a GIS is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modeling, representation and display of georeferenced data to solve complex problems regarding planning and management of resources. The functions of GIS include data entry, data display, data management, information retrieval and analysis. A GIS includes hardware, operating personnel, data and software. Data used in GIS are geo-referenced data. These data stored in tabular form represent features with descriptive and location attributes. Geo-referenced data can be stored in a vector graphics (points, lines (arcs), and polygons) or a raster graphics format. Using a vector format, two-dimensional location attribute is stored in terms of x and y coordinates (latitude/longitude, UTM, etc.). A road or a river can be described as a series of x,y coordinate points. Nonlinear features such as town boundaries can be stored as a closed loop of coordinates. The vector model is good for describing well-delineated features. A raster data format expresses data as a continously-changing set of grid cells. The raster model is better for portraying subtle changes such as soil type patterns over an area. Most geographic information systems make use of both kinds of data. GIS can be used for scientific investigations, resource management, and development planning.

3.3.2 Remote Sensing

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon under investigation(Lillesand and Kiefer, 2000).

A remote sensing system includes four components: a target, an energy source, a transmission path, and a sensor.

- The target is the object,area or phenomenon that is being studied.
- The energy source illuminates or provides electromagnetic energy to the target and act as a medium for transmitting information from the target to the sensor
- The sensor is a a remote device that will collect and record the electromagnetic radiation. Sensors can measure energy emitted by the target, reflected off of

the target, or transmitted through the target. Once the energy has been recorded, the resulting set of data must be transmitted to a receiving station where the data are processed into a usable format, which is most often as an image. The image is then interpreted in order to extract information about the target. This interpretation can be done visually or electronically with the aid of computers and image processing software. (http://earthobservatory.nasa.gov/Features/GlobalFire/fire_2.php)

3.3.3 DSS and SDSS Definitions

Decision Support Systems (DSS) are computer-based information systems designed to help managers solve problems in semi-structured decision-making areas(Meador et al., 1986). a DSS is an interactive software-based system intended to help decision makers compile useful information from raw data, documents, personal knowledge, and/or business models to identify and solve problems and make decisions. The conceptualization of Decision Support System (DSS) comes from the work by Simon and associates in 1950s and 1960s (Simon, 1960). Simon (1960) suggests that any decision-making process can be structured into three major phases: intelligence, design and choice. Malczewski (1997) explains that the intelligence phase imply searching or scanning the environment for conditions calling for decisions. The "design phase" involves inventing, developing and analyzing a set of possible decision alternatives for the problem identified in the intelligence phase, and the "Choice phase" involves selecting a particular decision alternative from those available; each alternative is evaluated and analyzed in regards with others in terms of particular decision rules. Many definitions of DSS require the presence of certain characteristics. Geoffrion (1983) suggests six characteristics of a Decision Support System: first a DSS is designed to solve ill- or semi-structured problems, that is, where objectives cannot be fully or precisely defined. Second, it has an interface that is both powerful and easy to use. Third, it enables the user to combine models and data in a flexible manner. Fourth, it should help the user explore the solution space (the options available to them) by using the models in the system to generate a series of feasible alternatives. Fifth, it should support a variety of decision-making styles, and easily adapted to provide new capabilities as the needs of the user evolve and finally problem solving is an interactive and recursive process in which decision making proceeds by multiple passes, perhaps involving different routes, rather than a single linear path. During the three last decades, DSS evolved as a field of research, development, and practice (Sprague and Watson, 1996; Dargam and Zaraté, 2006). The SDSS concept has evolved in parallel with DSS. Densham (1994) defined a DSS as a geoprocessing system designed to support the decision research process for complex spatial problems. SDSS differs from DSS in sense that it includes a spatial component. The development of SDSS has been associated with the need to expand the GIS capabilities for tackling complex, ill-defined, spatial decision problems (Densham and Goodchild, 1989); IBM's Geodata Analysis and Display System (GADS) - developed in the 1970s - was one of the earliest large DSS (Sprague and Watson, 1996); The field has now grown to the point that it is made up of many tasks with different, but related names, such as collaborative SDSS, group SDSS, environmental DSS, spatial knowledge based and expert systems. These characteristics listed above for DSS also define a SDSS. In addition, in order to effectively support decision- making for complex spatial problems, a SDSS will need to:

- be adapted to the specificity of spatial data.
- allow storage of complex structures common in spatial data
- include analytical techniques that are unique to spatial analysis
- provide output in the form of maps and other spatial forms.

Many authors have defined the components of a SDSS. According to Armstrong and Densham (1990), these component may be gathered in five key: 1. a database management system (DBMS) 2. analysis procedures in a model base management system (MBMS) 3. a display generator 4. a report generator 5. a user interface.

3.3.4 Fires in vegetation

Fires in vegetation include those fires in forests, woodlands, rangelands and interfaces between agriculture and forestry and between wildland and residential/urban areas.

3.3.5 Fire management

Fire management encompasses all activities related to fire protection (early warning), preparedness, prevention, response and suppression, restoration/rehabilitation and monitoring (FAO, 2007a)

3.3.6 Fire-break

Fire breaks are measure set to control propagation of fire. The function of a fire-break is to create discontinuity in forest to reduce the intensity of fire and to struggle efficiently at precise points against fire. There should be set on very restraint areas to be effective. They could generate though erosion. The choice of the type of firebreak depends on the type of soil, the investments and the needs and availability of the populations.

There are four types of firebreak (Arbonnier and Faye, 1988)

- The bare firebreaks : they are effective on narrow area of about 30m in width and on hard-pan lateritic soil.
- firebreak under cultivation: they are areas which are cultivated with court period plants. The residues are cleaned after harvest. It is noticed that the production of plants decreased over times.
- Firebreak under natural vegetation : they supplement 5m-wide bare firebreak and are made of area covered with natural vegetation which is every year early burnt.

- Wooded firebreak are made of planted tree on the area in concern. Trees with small leaves are recommended. The litter created under this vegetation by this kind of leaves does not burn easily. They prevent weed for growing under the trees.

3.3.7 Fire prevention

Prescribed burning: Prescribed burns are considered as the intentional ignition of grass, shrub, or forest fuels for specific purposes according to predetermined conditions. Fires burning early in the dry season tend to be of low intensity as the predominantly herbaceous fuel still holds moisture from the wet season ((Liedloff et al., 2001)). These fires often burn in a patchy manner and while removing litter and much of the grass layer, they have little effect on the vegetation the following year (Williams et al., 1999).

3.3.8 Fire prohibition

Complete prohibition of fire is impossible: the culture of fire is entrenched in the people's way of life. Massive environmental education programme is recommended rather than enactment of decrees.

3.3.9 Fire regime

The National Wildfire Coordinating Group (1996) defined fire regime as the periodicity and pattern of naturally-occurring fires in a particular area or vegetatvie type, described in terms of frequency, biological severity, and area extent. Hence fire regime encompasses fires attributes such as their intensity, their severity, the frequency with which they occur, the season in which they occur, their spatial pattern or extent, and their type (Bond and van Wilgen, 1996; International Forest Fire News (IFFN), 2003).

a) Fire intensity

   Fire intensity is defined as a measure of the time-averaged energy flux or, in other words, the energy per unit volume multiplied by the velocity at which the energy is moving; the resulting vector has the units of Wm^{-2} (Keeley, 2009). Fire intensity represents the energy released during various phases of the fire (Forest Encyclopedia Network, 2009; Prepas et al., 2010) and no single metric captures all of the relevant aspects of fire energy. Different metrics, including reaction intensity, fireline intensity, temperature, residence time, radiant energy and others are useful for different purposes. Fire intensity is a measure of the rate of heat released by a fire. It includes both radiant and convectional heat. Fire intensity affects ecological and geophysical processes in fire-prone landscapes.(Hammill and Bradstock, 2006)

b) Fire severity

   Fire severity refers to the loss or decomposition of organic matter aboveground and belowground. Fire severity is the measure of its impacts on biotic and abiotic components of the ecosystem subsequent to the vertical transfer of heat from surface to below the ground (Prepas et al., 2009; Rowe, 1983). It is the degree of removal of organic material and soil heating (Rowe, 1983). Fire severity is correlated with fire intensity. Since the definition of fire severity is rather general, this parameter has no fix operationally useful metrics (Keeley, 2009)

c) Fire frequency

Fire frequency is the number of fire event during a given time range. Fire periodicity can be determined by pollen counts, dendrochronology, and carbon deposition in lacustrine systems(Spurr, 1954). A wide variety of faunal groups are sensitive to habitat simplification resulting from fire frequency(York, 2000). Population extinction may occur if there are successive fires during a plant's juvenile period. Recurrent fires seriously impede the recovery of burnt forest and are a principal concern for the rehabilitation of dry forests. Obligate seeders rely on seeds for recovery from disturbance by fire and they are sensitive to regimes of frequent fire.

d) Fire season and timing

Fire season is determined by the begining date and the ending date of the fire episode. Vegetation fires that occur late in dry season or after drying events, are more severe than those that occur when vegetation is still growing. At the night available moisture condenses out of the cooler air, hence fire occurring at the night exhibit less severity of burning and results into unburned patches.

e) Fire extent or size

The area and volume of materials consumed by wildfire constitute the overall fire size (Prepas et al., 2009). Fire size can vary according to the cause and the location. Lightening induced fires that occur in remote areas can develop into large wildfires before detection. Human-caused fires often occur in or near populated areas where they are reported quickly and their effects are minimized before sizeable areas are burned (Prepas et al., 2009). However burning for agriculture purposes can occasionally develop into uncontrolled bush or crown fires.

f) Fire type

Fires are usually classified in three categories (Prepas et al., 2010): surface fire, intermitten crown fire and crown fire. Grass fires are usually surface. They typically move at highest speeds but exhibit lowest impact. Intermittent crown fires have moderate impact and crown fire, moving at slower speeds, show the highest impact.

Table 3.1: Ranges of fire severity and intensity with associated fire types (source : Prepas et al. (2010))

Severity	(°C)	Intensity (KWh^{-1})	Associated fire type
Low	< 180	100-2000	Surface
Moderate	180-300	2000-10000	Intermittent crown
High	> 300	> 10000	Continous crown

3.4 Presentation of available fire monitoring and assessment methods

The fact that fire is a potential threat and a key biophysical environment disturbance results in development of a large spectrum of fire monitoring systems. These monitoring systems are not only national agencies and interagency initiatives but also from international institutions, research centres and universities. In this section an overview of those resources is provided.

The Canada Centre for Remote Sensing (CCRS) is the Government of Canada's centre of excellence for remote sensing and geodesy and the Canadian Forest Service is a science-based policy organization both within Natural Resources Canada, a Government of Canada department that helps shape the natural resources sectors important contributions to the economy, society and the environment. The Canadian Forest Service promotes the sustainable development of Canada's forests and the competitiveness of the Canadian forest sector. They operate country wide satellite-based fire monitoring system. The Canadian Wildland Fire Information System (CWFIS) is a computer-based fire management information system that monitors fire danger conditions across Canada. Daily weather conditions are collected from across Canada and used to produce fire weather and fire behavior maps. In addition, satellites are used to detect fires.

The US Forest Service employs rapid response data of the MODIS systems and data of their own Direct Readout station to distribute fire information on the Internet. They provide the users on Internet http://www.fs.fed.us/fire/planning/nist/ with a set of fire applications. That include:

- ALMS - the Automated Lightning Mapping System, an application that allows the user to get near real time lightning location information via Internet.
- BehavePlus - Fire Behavior Prediction and Fuel Modeling,which predicts and/or analyzes fire behavior for specified condition.
- FARSITE, a model for spatially and temporally simulating the spread of fires under conditions of heterogeneous terrain, fuels, and weather.
- FIMT - Fire Incident Mapping Tool, an extension for ARCGIS ArcMap version 9.x

South Africa's council for Scientific and Industrial Research (CSIR) with the Advanced Fire Information Service (AFIS) uses satellite data combine with mobile

Table 3.2: Some fire applications provided by US Forest Service

Application Name	Description
ALMS	Automated Lighning Mapping System
BEHAVEPLUS	Fire Modeling System
FARSITE	Fire Area Simulator
FEIS	Fire Effects Information System
FIMT	Fire Incident Mapping Tool
FIREBUDGET2	
FIREFAMILY PLUS	
FIRESTAT	Fire Statistics
FPA	Fire Program Analysis
FOFEM	First Order Fire Effects Model
KCFAST	Kansas City Fire Access Software & PC and WEB application
NFMAS	National Fire Management Analysis System
NIFMID	National Interagency Fire Management Integrated Database
NIFSIP	National Interagency Fire Statistics Information Project
RXBURN/RXWEATHER	Prescribed Fire Behavior Prediction
WFAS	Wildland Fire Assessment System

phone technology to provide crucial early warnings to local disaster managers, and interested users. Fires as small as 50 m^2 can be detected.

The Brazil's National Institute for Space Research (INPE) built a system on the MODIS/RapidResponse images that provides fire information for South America ((Instituto Nacional de Pesquisas Espaciais(INPE), 2008)). It presents query based on-line fire monitoring system for countries of south America. The user can get the mapping of fire from various NOAA, GEOS, MODIS, GEOS satellites along with others climatic information for the specified area. The fires information can be exported as shape file, html or text format.

Sentinel Asia is initiated to support disaster management activity in the Asia-Pacific region by applying the WEB-GIS technology. Its provides wildfire hotspot information along with meteorological satellite imagery and data (http://sentinel.tksc.jaxa.jp/sentinel2/MB_HTML/About/About.htm).

PYROSTAT, a computer program for forest fire data inventory and analysis in Mediterranean countries is designed to electronically file forest fire information and produces reports with cumulative quantitative data on forest fires (number of fires, area burned, fire causes, type of vegetation burned, fire suppression parameters, etc.), at various temporal (single day, month, year or multi-year) and spatial (local, regional, national) scales. It also provides the user with the option to isolate, group and retrieve recorded fires that share in common a combination of factors.

Although those above listed fire management decision support tools can be a source of inspiration for similar development, they are implemented to solve local

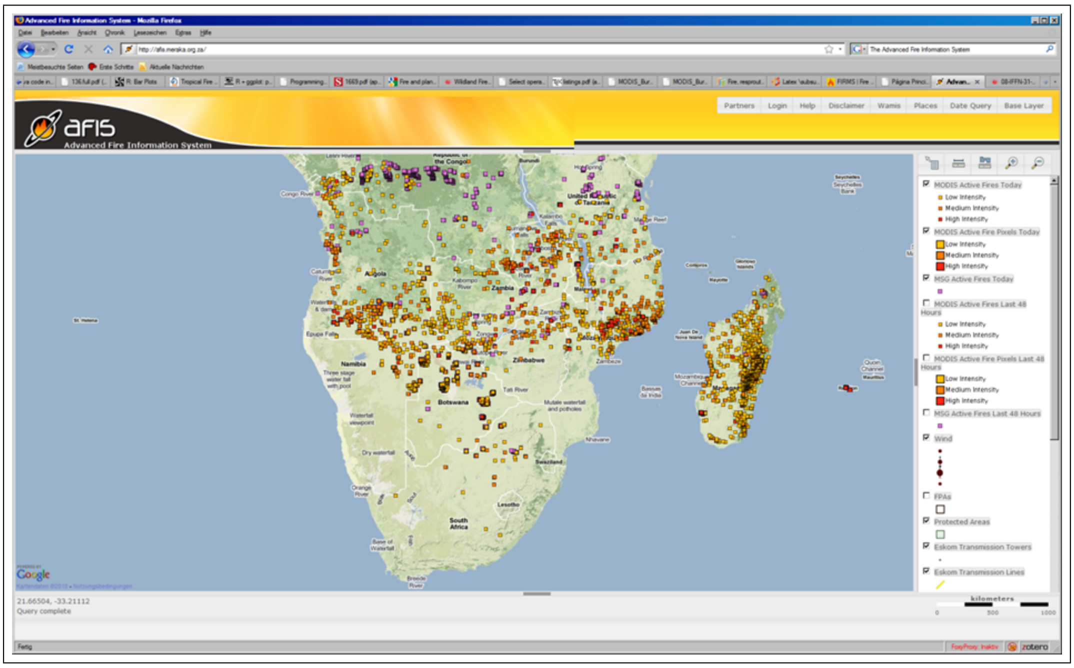


Figure 3.2: Screen snapshot of the South-African Advanced Fire Information Service (AFIS) (Source: http://afis.meraka.org.za/)

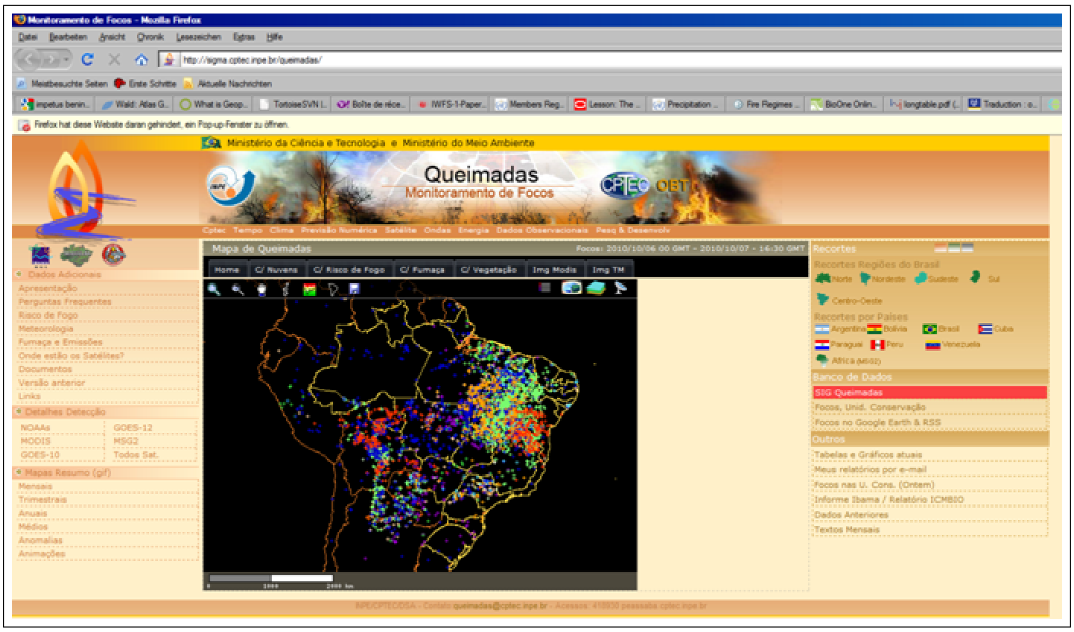


Figure 3.3: Screen snapshot of the Brazilian INPE fire monitoring system (source : Website http://sigma.cptec.inpe.br/queimadas/index_in.php)

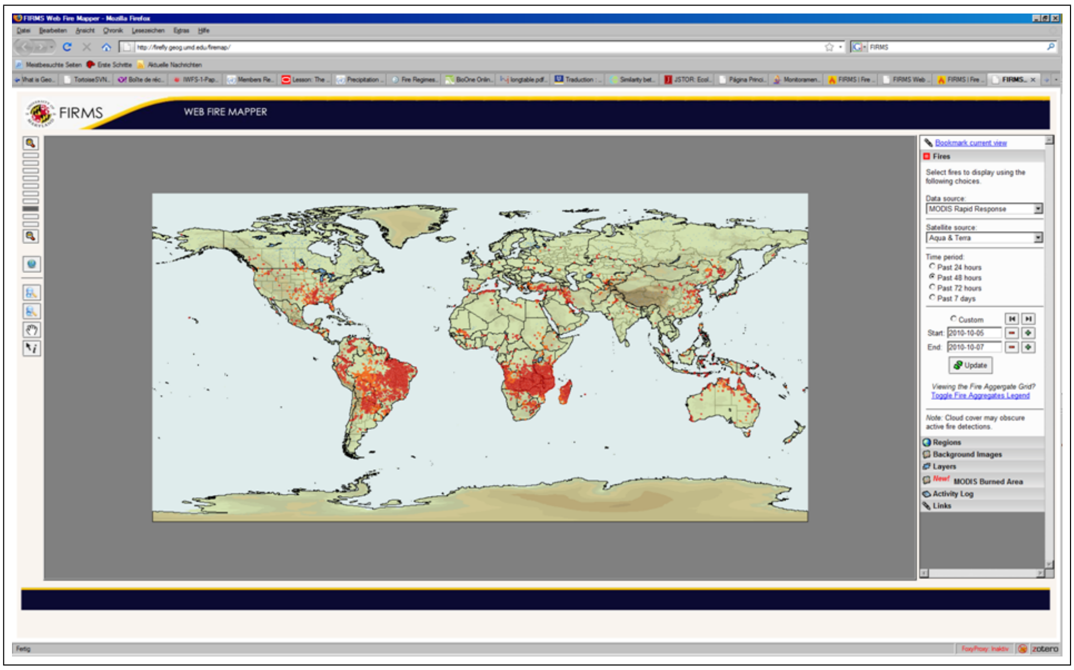


Figure 3.4: Screen snapshot of the Fire Information for Resource Management System of University of Maryland (source : http://firefly.geog.umd.edu/firemap/)

fire issue and are not applicable to our study area Benin. The following one are global and they are usable in Benin. Nevertheless they need some additional features whose implementation are valuable in context of fire in Benin. Those features, as mentioned later, are parts of the contributions of this work to the matter.

The Fire Information for Resource Management System of NASA (FIRMS : http://firefly.geog.umd.edu/firemap/) integrates remote sensing and GIS technologies to deliver global MODIS hotspot/fire locations to natural resource managers and other stakeholders around the World.

It is funded by NASA and builds on Web Fire Mapper, a web mapping interface that displays hotspots/fires provided by the MODIS Rapid Response System. It is developed to distribute near real-time hotspot/fire information in various formats to international users and support fire managers around the World. FIRMS delivers active fires detected using the MODIS active fire locations processed by the MODIS Rapid Response System. The active fire locations are processed by the MODIS Rapid Response System using the standard MODIS MOD14/MYD14 Fire and Thermal Anomalies Product. Each active fire location represents the center of a 1 km pixel that is flagged by the algorithm as containing a fire within the pixel. FIRMS offers the possibility of email alerts. It has integrated burned area data very recently (2010). The user cannot overlay other own ancillary layers to the generated map.

The Global Fire Monitoring Center (GFMC) hosted at university of Freiburg in Germany and designed as an information and monitoring facility for planning and decision making, provides a global portal for wildland fire documentation, information and monitoring. It is accessible through the Internet at the address http://www.fire.uni-freiburg.de/ . The regularly updated national to global wildland fire products of the GFMC are generated by a worldwide network of cooperating institutions. The online and offline products include:

- Early warning of fire danger and near-real time monitoring of fire events
- Interpretation, synthesis and archive of global fire information
- Support of local, national and international entities to develop long-term strategies or policies for wildland fire management, including community-based fire management approaches and advanced wildland fire management training for decision makers
- Serve as advisory body to the UN system through the coordination of the UN-ISDR Wildland Fire Advisory Group and the ISDR Global Wildland Fire Network
- Emergency hotline and liaison capabilities for providing assistance for rapid assessment and decision support in response to wildland fire emergencies under cooperative agreements with UN-OCHA, Emergency Services Branch and the WSSD Environmental Emergencies Partnership.

The World Fire Atlas (WFA) is a global active fire provided by Along-Track Scanning Radiometer (ATSR-2) and Advanced Along-Track Scanning Radiometer (AATSR) sensors on board of European Remote Sensing Satellite (ERS) and Environment Satellite (ENVISAT) respectively. The product have a spatial resolution of 1km at the nadir and an equatorial revisiting of 3 days. The data are available since November 1995 and extends to the present. The data acquired at nighttime so fire burning during the daytime are not recorded.

3.5 Various available active fire and burned area products

Recently many fire products have been developed and made available to scientific community. This section provides a summary of the features of available fire products and assess their quality relative to fire management. Each product shows specific advantages and some limitations.

3.5.1 Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire

The MODIS Active Fire products are part of the suite of terrestrial products acquired by MODIS sensors on board of TERRA and AQUA satellite. They provide information about actively burning fires, including their location and timing, instantaneous radiative power, and smoldering ratio, presented at a selection of spatial and temporal scales (Giglio et al., 2003; Justice et al., 2002; Kaufman et al., 1998).

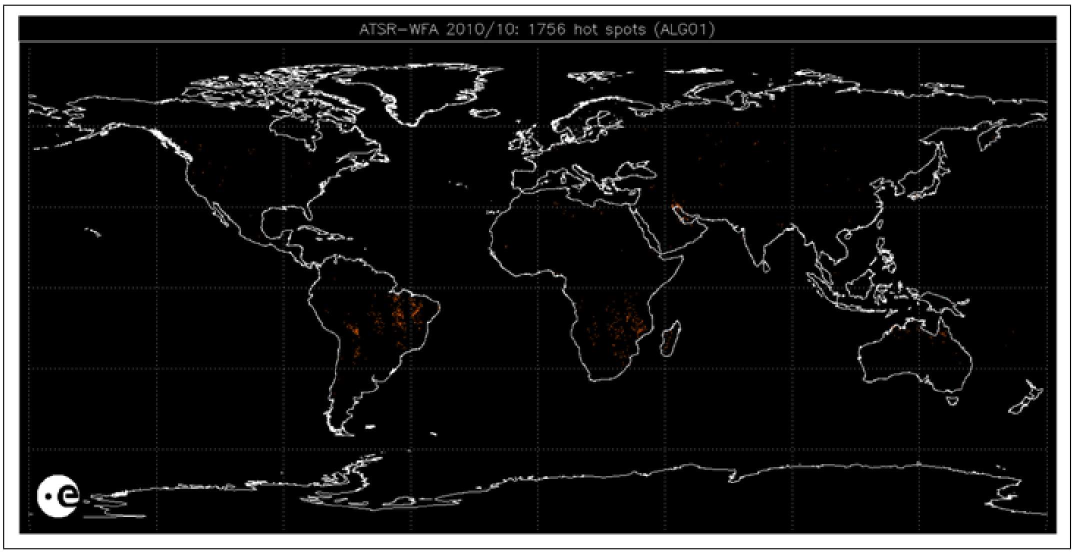


Figure 3.5: The World Fire Atlas (source: WFA Website http://wfaa-dat.esrin.esa.int/)

The products present a quite good spatial resolution of 500 meters. The active fire algorithm uses multiple channels to detect thermal anomalies on a per-pixel basis (Giglio et al., 2003).

A near real-time assessment of fire can be also made thanks to its daily temporal resolution. Yet some fires can be missed when they happened after the passing of the satellite. The data are available since 2000 but not enough for times series analysis.

3.5.2 MODIS burned area product

The MODIS burned area product is a level 3 product derived from processing of combined MODIS-TERRA and MODIS-AQUA 500m land surface reflectance data. The algorithm used to generate the product follows a bi-directional reflectance (BRDF) model-based change detection approach. This algorithm detects the approximate date of burning by locating the occurrence of rapid changes in daily MODIS reflectance time series. The product is organized in tile each covering approximately an area of 1200km x 1200km (10°x 10°at the equator). The projection system is sinusoidal. (Roy et al., 2008b) The product contains the followings:

- Per-pixel burning information
  - The approximate day of burning (1-366) or (no burning detected)
  - Codes to indicate no decision due to persistent missing, bad quality or cloudy data
  - QA information

- Mandatory and product-specific metadata

3.6 Conclusion

This chapter gives the clarification of some key concepts related to the topic of the study and provides an insight into fire ecology. Fire ecology study the behavior and relation of fire with other element of ecosystem. A short description of those relationships is given. That helps to understand that fire is not only a disturbance of ecosystem but it is integrated to the function of this ecosystem. Once this importance of fire for ecosystem is understood, The importance of wildland fire in ecosystem and its implications for human being is grasped and a sustainable management of fire proves to be necessary. An effective management requires reliable and objective information to base on. The awareness of that requirement results in development of a set of methods and tools in spatial decision support for fire management. The specific advantages and some limitation of those resources have been assessed. Some of the presented resources are dedicated to specific location, thus can not be used directly for Benin. They are though source of inspiration for similar projects. Other are global and can be directly used for Benin but need development of additional features.

Chapter 4

Data and Methods

The first part of this chapter gives a general description of MODIS products with a focus on MODIS burned area product which is the main data used for our study. The second part explains the approaches followed to created the SDSS FIMAT and how it is used to characterise bush fire in Benin.

4.1 Data

The Moderate Resolution Imaging Spectroradiometer (MODIS) Burned area product (MCD45A1) along with other ancillary data such as: protected areas, land cover, rainfall time series, the road network and communes are used.

4.1.1 MODIS Data product levels description

MODIS data are generated, processed and released at various processing levels. It is important to understand the meaning of the different product levels. Thus, a brief explanation of these levels follows. Level 0 refers to reconstructed, unprocessed instrument/pay-load data at full resolution. It includes all communications artifacts, e.g., synchronization frames, communications headers. Level 1A- is a reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters. Level 1B product is a Level 1A data that have been processed to sensor units. It is a swath (scene) of MODIS data geolocated to latitude and longitude centers of 1 km resolution pixels. it has not been temporally or spatially manipulated. Level 2 data refers to the derived geophysical variables at the same resolution and location as the Level 1 data. In Level 3, variables are mapped on uniform space-time grid scales, usually with some completeness and consistency . Level 3 is usually in a gridded map projection format referred to as tiles. Each tile is a piece, e.g., about 1113 km by 1113 km in 1200 rows by 1200 columns, of a map projection. Level 4 are model output or results from analyses of lower level data, e.g., variables derived from multiple measurements.

4.1.1.1 MODIS Burned Area Monthly L3 Global 500m Grid, Version 5

The MODIS Burned Area Monthly L3 Global 500m Grid (MCD45A1) data set contains data fields for Burned Area extent over on month compositing period and a chronology of approximative fire occurrence observations in compressed Hierarchical Data Format-Earth Observing System (HDF-EOS) format, along with corresponding metadata. MCD45A1 consists of 1200 km by 1200 km tiles which corresponds to 2400 pixels by 2400 pixels of 500 m resolution data gridded in a sinusoidal map projection. Coverage is global. MODIS Burned Area data are based on a fire mapping algorithm that employs a Normalized Difference fire Index (NDSI) and other criteria tests based on the brightness temperature of pixels (Roy et al., 2008b).

4.1.1.2 Format

MODIS burned area products are archived in compressed HDF-EOS format, which employs point, swath, and grid structures to geolocate the data fields to geographic coordinates. This data compression should be transparent to most users since HDF capable software tools automatically uncompress the data. Various software packages, including several in the public domain, support the HDF-EOS data format (See Tools for accessing and analyzing section 4 for details). the Hierarchical Data Format - Earth Observing System (HDF-EOS) Web (http://hdfeos.org/)site for more information about the HDF-EOS data format, as well as tutorials in uncompressing the data and converting data to binary format. Data are stored in HDF-EOS format, and are available from 24 February 2000 to present via FTP(see details in subsequent sections). Data file size of a tile is typically between 0.5 - 3 MB using HDF compression. Data can also be obtained in GeoTIFF format by ordering the data through the Data Pool.

4.1.1.3 File Naming Convention

The following file naming convention is common to all Level 3 MODIS Land products: MCD45A1.A2003138.h03v06.005.2006.143062148.hdf

Table 4.1: Variable Explanation for MODIS File Naming Convention)

Variable	Explanation
MCD	AQUA/Terra
MCD45A1	Type of product
A	Acquisition date
2003	Year of data acquisition
138	Day of year of data acquisition (In this case, day 138. The date in the granule is the first day of data in the monthly file.)
h18v07	Horizontal tile number and vertical tile number. See the MODIS Sinusoidal Grid (SIN) as a reference.
005	Version number
2006	Year of production (2006)
143	Day of year of production (Day 143)
062148	Hour/minute/second of production in Greenwich Mean Time (GMT) (06:21:48)
hdf	HDF-EOS data format

MOD09A1.A2006001.h08v05.005.2006012234657.hdf;

The MODIS Long Name (i.e., Collection-Level) convention also provides useful information. For example, all products belonging to the **MODIS/Terra Surface Reflectance 8-Day L3 Global 500m SIN Grid V005 collection** have the following characteristics:

- **MODIS/Terra - Instrument/Sensor**
- **Surface Reflectance - Geophysical Parameter**
- **8-Day - Temporal Resolution**
- **L3 - Processing Level**
- **Global - Global or Swath**
- **500m - Spatial Resolution**
- **SIN Grid - Gridded or Not**
- **V005 - Collection Version**

Algorithms that generate Burned Area products are continually being improved as limitations become apparent in early versions of data. As a new algorithm becomes available, a new version of data is released. The most current version of data available, has the highest version number. Version 5 (V005), also known as Collection 5, is the most current version of MODIS data available from the National Snow and Ice Data Center (NSEDC).

4.1.1.4 Tools for accessing and analyzing data

- Land Processes Distributed Active Archive Center (LP DAAC) (https://lpdaac.usgs.gov/lpdaac/tools/)
- MODIS Rapid Response System (http://rapidfire.sci.gsfc.nasa.gov/)
- NASA Goddard Space Flight Center: MODIS Land Global Browse Images(http://www.nasa.gov/centers/goddard/home/index.html)
- Land Processes Distributive Active Archive Center: MODIS Reprojection Tool Distribution Page: Software tools that reproject MODIS data from sinusoidal EASE-Grid or Climate Modeller's Grid projections to other projections.
- HEG HDF-EOS to GeoTIFF Conversion Tool : a free tool which converts different types of HDF-EOS data to GeoTIFF, native binary, or HDF-EOS grid format. It also has reprojection, resampling, subsetting, stitching (mosaicing), and metadata creation capabilities.
- National Center for Supercomputing Applications (NCSA) HDFView: The HDFView is a visual tool for browsing and editing the HDF4 and HDF5 files. Using HDFView, you can view a file hierarchy in a tree structure, create a new file, add or delete groups and datasets, view and modify the content of a dataset, add, delete, and modify attributes, and replace I/O and GUI components such as table view, image view, and metadata view.

- Hierarchical Data Format - Earth Observing System (HDF-EOS): NSIDC provides more information about the HDF-EOS format, tools for extracting binary and ASCII objects from HDF, information about the hrepack tool for uncompressing HDF-EOS data files, and a list of other HDF-EOS resources.
- The MODIS Conversion Toolkit (MCTK): A free plugin for ENVI that can ingest, process, and georeference every known MODIS data product using either a graphical widget interface or a batch programmatic interface. This includes MODIS products distributed with EASE-Grid projections.

4.1.1.5 Contents of the MODIS Burned Area Product

Each data file contains the following HDF-EOS local attribute fields, which are stored with their associated Scientific Data Set (SDS):

1. Burn date data Sample Value Code (2 bytes):
    - 0 - unburned
    - 1-366 - approximate Julian day of burning within the month
    - 900 - snow or high aerosol
    - 9998 - water bodies (internal)
    - 9999 - water bodies (seas and oceans)
    - 10000 - not enough data to perform inversion throughout the period
    - 32768 - pixel not covered by any MODIS tile
2. BA pixel Quality assessment (QA) (1 byte):Confidence of the detection (1 refers to most confident, 4 to least confident.)
    - most confidently detected pixels, regardless of direction in time (forward, backward or both), passing test (4) described in appendix D.
    - pixels where backward and forward direction in time predict the same change, passing test (5) described in appendix D.
    - pixels selected in the first stage of the contextual analysis.
    - pixels selected in the second stage of the contextual analysis.
    - number of Passes (1 byte): number of observations where the temporal consistency test is passed.
    - number Used (1 byte): number of observations used in the temporal consistency test.
3. Direction (1 byte):Direction in time in which burning was detected (forward, backward or both).

- 1 - forward
- 2 - backward
- 3 - both

4. Surface Type (1 byte): Information describing the land cover type and properties. The information is stored in the individual bits of the layer.
    - bit 0 (1=yes, 0=no): - water (NDVI < 0.1 and The band 7 of the reflectance product(b7) < 0.04)
    - bit 1 (1=yes, 0=no) - low NDVI (NDVI < 0.1)
    - bit 2 (1=yes, 0=no) - shallow, ephemeral, deep inland water (QA from MOD09 = 3, 4, 5 AND NDVI <0.1)
    - bit 3 (1=yes, 0=no) - cloud (from MOD09 internal cloud mask)
    - bit 4 (1=yes, 0=no) - cloud shadow (from MOD09 internal cloud mask)
    - bit 5 (1=yes, 0=no) - view and solar zenith angle mask (Vz > 65 threshold or Sz > 65)
    - bit 6 (1=yes, 0=no) - high view and solar zenith angle (Vz > 50 and Sz > 55)
    - bit 7(1=yes, 0=no) - snow OR [high aerosol (from MOD09 QA) AND high view / solar zenith (Vz > 55 and Sz > 55)] Example: if the Surface Type value of a pixel is 18, the corresponding binary number is 01001000; as bits 1 and 4 are set to 1, it means low NDVI and cloud shadow detected.
5. Gap Range 1 (2 bytes): Information describing the largest number of consecutive missing/cloudy days (if any) in the time series and the start day of the missing/cloudy period. bits 0-8 - Julian day of the start of the gap bits 9-13 - number of missing days including the start day Example: if the pixel value is 3372, the corresponding binary number is 001101001011000. The first nine bits (001101001) represent the number 300, the four following bits (0110) represent the number 6. Hence a six day gap starting at Julian day 300.
6. Gap Range 2 (2 bytes): Information describing the second largest number of consecutive missing/cloudy days (if any) in the time series and the start day of the missing period. bits 0-8 - Julian day of the start of the gap bits 9-13 - number of missing days including the start day

Quality Assessment The Burned Area Pixel QA mentioned above stands for Quality indicators. Indeed, Quality indicators for MODIS burned area are provided as Scientific Dataset layer within the product file. It is a 8-bit integer layer with value ranging from 1 to 4. The values are described as stated above.

4.1.1.6 MCD45A1 Metadata

Each tile also contains metadata either stored as global attributes or as HDF-predefined fields, which are stored with each SDS. In addition to the mandatory metadata required by the EOS Data Information System (EOSDIS) Core System (ECS), a set of product specific, tile-level metadata are included to enable the burned area product to be archived and ordered via ECS DAAC ordering systems. The metadata report for each tile includes: The percentage of land pixels detected as burned. The percentage of pixels not processed due to insufficient cloud-free data. The percentage of pixels in each of the BA pixel QA categories. The number of pixels detected in each direction in time (forward, backward or both).

A separate ASCII text file containing metadata with a .xml file extension accompanies the HDF-EOS file. The metadata file contains some of the same metadata as in the product file, but also includes other information regarding archiving, user support, and post-production Quality Assessment (QA) relative to the granule ordered. The post-production QA metadata may or may not be present depending on whether or not the data granule was investigated for quality assessment. The metadata file should be examined to determine if post-production QA was applied to the granule (Riggs, Hall, and Salomonson 2003).

4.1.1.7 Latitude Crossing Times

The local equatorial crossing time of the Terra satellite is approximately 10:30 A.M. in a descending node with a sun-synchronous, near-polar, circular orbit(see Figure 4.1 and 4.2).

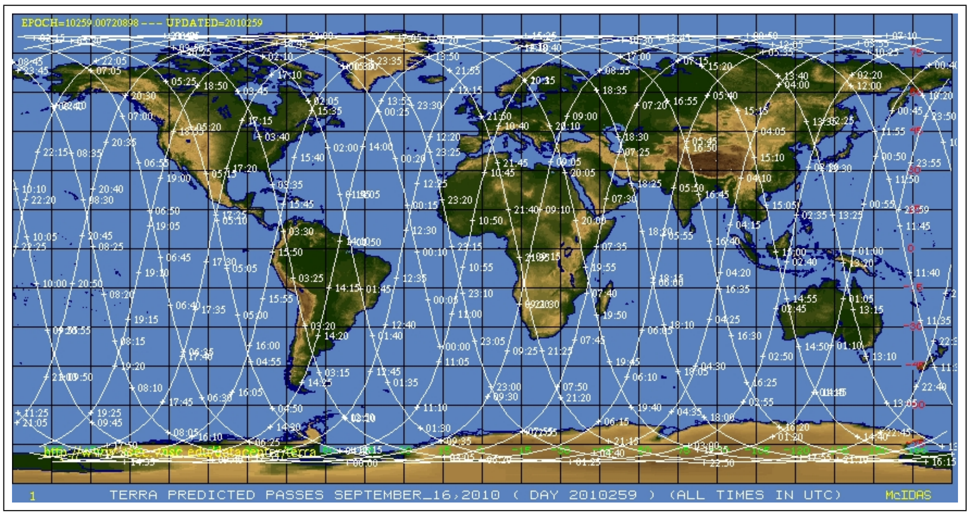


Figure 4.1: Terra predicted passes September 16, 2010 (all times in UTC, source : http://www.ssec.wisc.edu/datacenter/terra/archive/)

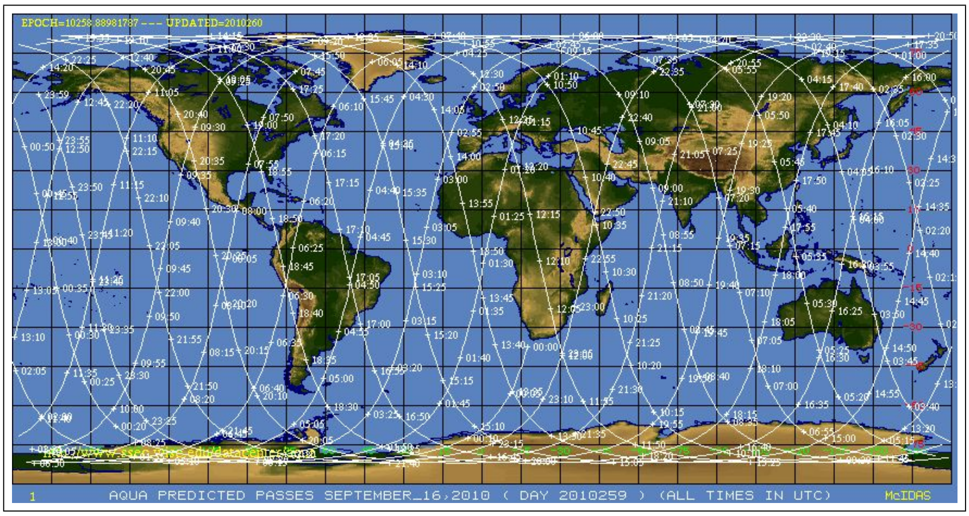


Figure 4.2: Aqua predicted passes September 16, 2010 (all times in UTC, source : http://www.ssec.wisc.edu/datacenter/aqua/archive/)

4.1.1.8 Projection

MODIS Land (MODLAND) V005 data are georeferenced to an equal-area sinusoidal projection. The following Web sites provide links to the software tools that either read data in a sinusoidal projection or convert sinusoidal to other projections:

- Earth Observing System Data and Information System (EOSDIS) Core System Project: Science Data Processing (SDP) Toolkit Home Page (http://esdis.eosdis.nasa.gov/)
- LP DAAC: MODIS Reprojection Tool Distribution Page (https://lpdaac.usgs.gov/lpdaac/tools/modis_reprojection_tool)
- Trailane: Tools for Referencing and Conversion()
- HEG HDF-EOS to GeoTIFF Conversion Tool
- RSI ENVI/IDL (http://www.rsinc.com/)
- ERDAS Imagine (http://gis.leica-geosystems.com/)
- PCI Geomatics (http://www.pcigeomatics.com/)
- Idrisi (http://www.clarklabs.org/)
- ERMapper (http://www.ermapper.com/)
- Matlab (http://www.mathworks.com/)
- HDF Explorer Pro (http://www.space-research.org/)

More details can be found at the Land processes distributed active archive center https://lpdaac.usgs.gov/lpdaac/tools for more details

In the sinusoidal projections, areas on the data grids are proportional to the same areas on the Earth, and distances are correct along all parallels and the central meridian. Shapes are increasingly distorted away from the central meridian and near the poles. Finally, the data are neither conformal, perspective, nor equidistant (USGS 2000).

Meridians are represented by sinusoidal curves (except for the central meridian), and parallels are represented by straight lines. The central meridian and parallels are straight lines of true scale (Pearson 1990). Specific parameters are listed in table4.2. Although this product is referred to as having a 500 m grid, the true pixel resolution is 463.31271653 m in both X and Y directions. Refer to Table 4.2. This allows for 2400 pixel by 2400 pixel tiles, each tile covering exactly 10 degrees of latitude vertically.

Table 4.2: Sinusoidal Projection Parameters)

Earth radius	6371007.181000 meters
Projection origin	0° latitude, 0° longitude
Orientation	0° longitude, oriented vertically at top
True scale (m)	463.31271653(x), 463.31271653(y)

4.1.1.9 Monthly Input Periods

MCD45A1 product are monthly composite of daily data. The month periods begin on the first day of the year and extend into the next year. The data file name indicates the first day in the month.

Table 4.3: MCD45A1)

Month	non-leap year	leap year
1	1	1
2	32	32
3	60	61
4	91	92
5	121	122
6	152	153
7	182	183
8	213	214
9	244	245
10	274	275
11	305	306
12	335	336

4.1.1.10 Data processing steps

The MODIS algorithm detects the approximate date of burning by locating where rapid changes in daily 500m surface reflectance time series data appear. It is an improvement on previous methods, through the use of a bidirectional reflectance model to deal with angular variations found in satellite data and the use of a statistical measure to detect change probability from a previously observed state. MODIS reflectance sensed within a temporal window of a fixed number of days is used to predict the reflectance at a following day. A statistical measure is used to determine if the difference between the predicted and observed reflectance is a significant change of interest e.g (Miettinen, 2007). Rather than attempting to minimize the directional information present in wide field-of-view satellite data by compositing, or by the use of spectral indices, this information is used to model the directional dependence of reflectance . This provides a semi-physically based method to predict change in reflectance from the previous state. A temporal constraint is used to identify and remove temporary changes, such as shadows, that are spectrally similar to more persistent fire induced changes. Further details are provided in Roy et al. (2005).

The algorithm tests for a variety of anomalous conditions and sets the pixel value accordingly if such conditions are detected. Summary statistics about missing data, the percent cloud cover, the percent of good or other quality data, and Burned Area percent are calculated and placed in the metadata for each product.

The NASA Goddard Space Flight Center: MODIS Land Quality Assessment Web site provides updated quality information for each product.

4.1.1.11 Data Acquisition : principles of operation

MODIS is a key instrument aboard the Terra satellite, the flagship of NASA Earth Observing System (EOS). The MODIS instrument provides 12-bit radiometric sensitivity in 36 spectral bands, ranging in wavelength from 0.4 μm to 14.4 μm. Two bands (bands 1-2) are imaged at a nominal resolution of 250 m at nadir, five bands (bands 3-7) at 500 m, and the remaining bands(bands 8-36) at 1000 m. A $\pm$55 degree scanning pattern at 705 km altitude achieves a 2330 km swath with global coverage every one or two days. MODIS sensor contains a system whereby visible light from the earth passes through a scan aperture and into a scan cavity to a scan mirror. The double-sided scan mirror reflects incoming light onto an internal telescope, which in turn focuses the light onto four different detector assemblies. Before the light reaches the detector assemblies, it passes through beam splitters and spectral filters that divide the light into four broad wavelength ranges. Each time a photon strikes a detector assembly, an electron is created. Electrons are collected in a capacitor where they are eventually transferred into the preamplifier. Electrons are converted from an analog signal to digital data, and downlinked to ground receiving stations (MODIS Web 2003).

4.1.1.12 Data calibration

MODIS has a series of on-board calibrators that provide radiometric, spectral, and spatial calibration of the MODIS instrument. The blackbody calibrator is the primary calibration source for thermal bands between 3.5 μm and 14.4μm, while the Solar Diffuser (SD) provides a diffuse, solar-illuminated calibration source for visible, near-infrared, and longwave infrared bands. The Solar Diffuser Stability Monitor (SDSM) tracks changes in the reflectance of the SD with reference to the sun so that potential instrument changes are not incorrectly attributed to changes in this calibration source. The Spectroradiometric Calibration Assembly (SRCA) provides additional spectral, radiometric, and spatial calibration.

MODIS uses the moon as an additional calibration technique and for tracking degradation of the SD by referencing the illumination of the moon since the moon's brightness is approximately the same as that of the Earth. Finally, MODIS deep space views provide a photon input signal of zero, which is used as a point of reference for calibration (MODIS Web 2003).

4.1.1.13 Data processing

The EOS Ground System (EGS) consists of facilities, networks, and systems that archive, process, and distribute EOS and other NASA earth science data to the science and user community. For example, ground stations provide space to ground communication. The EOS Data and Operations System (EDOS) processes telemetry from EOS spacecraft and instruments to generate Level-0 products, and maintains a backup archive of Level-0 products (ESDIS 1996). The NASA Goddard Space Flight Center: MODIS Adaptive Processing System (MODAPS) Services is currently responsible for generation of Level-1A data from Level-0 instrument packet data. These data are then used to generate higher level MODIS data products, including MCD45A1. MODIS fire data are available to the public through a variety of interfaces.

4.1.1.14 Data Collection System

All MODIS products are available free of charge. The MODIS Burned Area Product is available for ordering from the Land Processes Distributed Active Archive Center (LP-DAAC) using the EOS Data Gateway web interface located at: http://wist.echo.nasa.gov Additionally, an ftp server is maintained by the University of Maryland, mostly to provide support to the science users who need to download systematically large volumes of data.

4.1.1.15 Downloading the products via FTP

MODIS products can be downloaded directly via the NASA Land Processes Distributed Active Archive Center (LP-DAAC) anonymous FTP server (and ftp://e4ftl01u.ecs.nasa.gov/). In addition, the MODIS burned area product is available for download via ftp from the website http://modis-fire.umd.edu/ . The later ftp access required username and password. Thus, the users are requested to fill in a user online form for statistical purposes and in order to obtain the login parameters for the server. The form is available under http://modis-fire.umd.edu/form.asp . The data can be downloaded via the FTP extension of web browser such as Firefox or Internet Explorer. Using freely available special FTP software such as FileZillaClient or SmartFTP for downloading large amounts of data improves the speed though.

Whichever program you will use for data download you will need to connect to the given ftp site that is: ftp://ba1.geog.umd.edu

4.1.1.16 Data structure on ftp://ba1.geog.umd.edu FTP server

Both data sets HDF and geotiffs are available on the same FTP server. However, the subdirectory structure is different and is described in the following paragraphs.

HDF files The file system on the ftp server is structured to organize the data hierarchically by year and by month. All the data from the same month is located in a directory identified by the year and month as: /HDF/YYYY/DDD/
where: YYYY is the year DDD is the julian day of the beginning of the month
For example, the directory /HDF/2001/152 contains all the tiles (named with the convention explained in table 4.1) of the product for June 2001.

Geotiff files The file system on the ftp server is structured to organize the data hierarchically by window, and then by year. All the data for the same window from the same year is located in a directory identified as: /TIF/WinXX/YYYY/ where: XX is the number of the window (figure 2) YYYY is the year For example, the directory /TIF/Win01/2001 contains all the months of 2001 for window 01 (Alaska).

4.1.1.17 Data structure on ftp://e4ftl01u.ecs.nasa.gov/ FTP server

This server provides no geotiff file format. All the data are in HDF file format. Within the developed SDSS the data are downloaded from this FTP server. This option is chose because the access is anonymous thus it does not required password or username. Moreover, all other MODIS data can be got from that server as well. The hierarchy is the same for all products and depends on the time resolution of the product. Data are grouped by platform (MOLT for MODIS Terra, MOLA for MODIS aqua and MOLA for derived data). Each platform folder contains a sub folder of the product by version. Within this product-version sub folder are grouped the global data by date according to the time resolution of the product. For instance, for MODIS Burned area product (MCD45A1), the platform is both Terra and aqua because the product is generated from product of both platforms (MOLT). The time resolution of the file is a month. The counting starts from the first day of the year and the step is the time resolution. Hence, the data for the second month (February) of the year 2006 will be found at: MOLT/MCD45A1.005/2006.02.01/

4.2 Methods

Within this study, the following work steps is done (Figure 4.3): First there is an extended literature research within the field of SDSS and fire ecology to gain a theoretical base for further work. In the next step we define in collaboration with decision makers in Benin the demands of the planners. Thereby the used input parameter, the work flow of the decision process, the complexity of the user interface and the underlying computer system are evaluated. This research "which degree of complexity for whom" is quite an important topic which is embedded in and contribute to the "state of the art" theoretical concepts of SDSS and Fire ecology. The findings are discussed intensively with the scientists at the Remote Sensing Research Group and other members of the IMPETUS project and relevant groups in Benin.

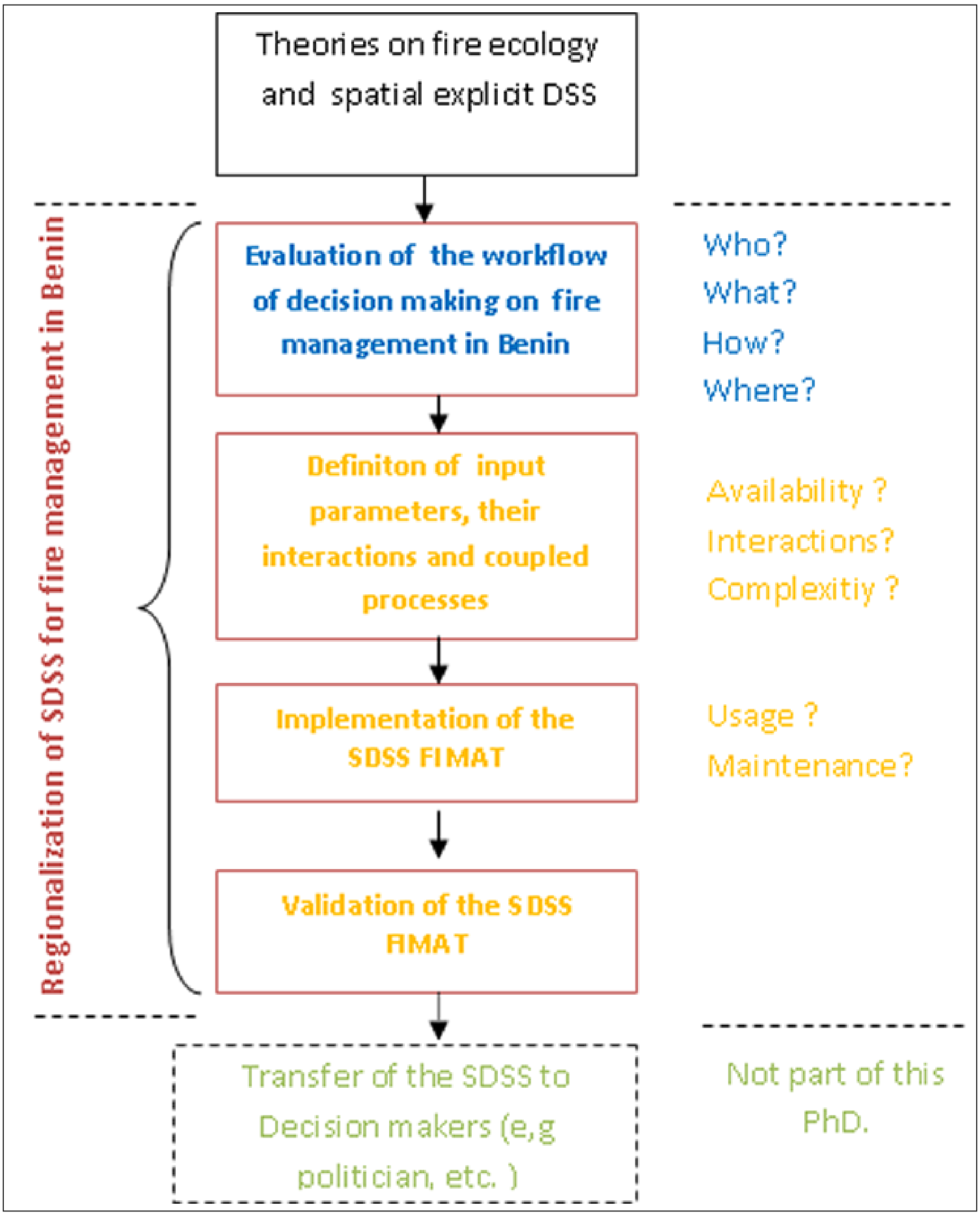


Figure 4.3: Workflow for the PHD

Table 4.4: Technical Specifications Orbit of MODIS sensor 705 km, 10:30 A.M. descending node (Terra)

Scan Rate	20.3 rp
Swath Dimensions	2330 km (cross track) by 10 km (along track at nadir)
Telescope with intermediate field stop	17.78 cm diameter off-axis, afocal (collimated)
Size	1.0m x 1.6m x 1.0 m
Weight	228.7 kg
Power	162.5 W (single orbit average)
Data Rate	10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)
Quantization	12 bits
Spatial Resolution	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)
Design Life	Six years

Based of these outcomes we regionalized the SDSS for bushfire management (FIMAT). Thereby spatial explicit information layers like digital elevation models, remote sensing data derived land use/land cover maps, model outcomes from land use/land cover maps, socio-economic data like population density and population projections are used as well as vector data like boundaries, rivers, cities and many other more. The interrelations of that various data layers are defined in queries.

4.2.1 The implementation of the decision support

The whole system is programmed in JAVA JDK 1.6.0 to enable that the system is widely independent from the used operation system of the computer. This gives as well the possibility to provide the SDSS in the Internet and to distribute them to a wide range of users or other interested groups. In Addition, that permits to benefit from available snippets of code and adapt to our case. See details in the chapter 5

4.2.2 Fire Dynamics

The seasons of fire are determined using the sequence of monthly images according to the raining season. Frequencies of burning events are calculated for each annual fire season from the MCD45A1 product within the program. Maps, charts, animations, tables are derived from these calculations. See details in chapter 6

4.2.3 Relation fires-land use

The raster of land use cover of 2004-2006 of ESA is used to describe the relation between the frequencies of fire and the type of land cover. This land cover raster of 300 m spatial resolution was generated using 19 months worth of data from Envisats Medium Resolution Imaging Spectrometer (MERIS) instrument (http://www.esa.int/esaEO/SEMXB7TTGOF_index_0.html). Data were collected between December 2004 and June 2006. A contingency table is generated from the raster of land use and the frequencies and a test of Chi square is performed. The goal was to describe the likelihood of burning according to the land cover. The same method is used to relate the earliness of burning to the land-use. See details in chapter 6

4.2.4 Relation fires and rainfall pattern

To relate the occurrence of fire to the burning importance,the data of annual rainfall from 2000 to 2007 are used. The total of burned area is related to the annual rainfall. The trends of rainfall and of annual burned area total are compared. See details in chapter 6 The next chapter, gives a review of the theories on fire ecology and “state-of-art” methods in spatial decision support system for fire management.

Chapter 5

Development of the SDSS for "Bush Fire" (FIMAT) based on Terra/Aqua MODIS time series datasets

5.1 Introduction

Vegetation fire is, as mentioned in former chapters, a major agent of environmental change and needs great consideration. It has implications on national, regional and global scale and requests the interest of decision makers. Making decision on fire management requires methodological and objective approaches including fire assessment and monitoring. These monitoring and assessment tasks are only effective with a systematic monitoring, accurate reporting and accessible information archiving. Moreover, open, transparent sharing of data and information on fires, their extent and distribution, causes and impacts are fundamental to effective international cooperation (International Forest Fire News (IFFN), 2003). In this chapter, our computer program called FIMAT for wildland fire data inventory and analysis is presented. It is a SDSS for wildland fire assessment, developed using Java developing language. The aim is to process the available information on fire and present the results – the necessary information natural fires managers and decision makers in Benin need to base their decisions on - in a simple format. This meets the need of a tool which can be operational even off-line, and which can enable the characterization of spatial and temporal patterns of burnt area along with various layers of data. Although the fire–tool is primarily developed with users in Benin in mind, it can be configured and used anywhere. The chapter is organized as follow: in the first section, data and methods used to develop the program are presented. Then we dive into the description of different elements of the Graphical User Interface. Finally, the usage of the whole system is shown.

5.2 Metrics and methods of the implementations

The whole project is written with Java Jdk 1.6.0. in Eclipse (http://eclipse.org/) and built with Maven. Apache Maven is a software project management tool used for building and managing any Java-based project. The project is made up with 55169 lines of code included in 402 Java classes. The classes are grouped in 32 packages. 44 third-party Java packages are used as dependencies and managed in local repository with Maven 2. The compiled executable jar file is 45MB big. The optimal running of the software requires an up to date desktop. 1GB of memory and 1Ghz CPU is a minimum. Enough free disk space is also needed. To run the program for the period 2000-2009, about 50GB are needed for data storage.

5.2.1 Description of the process algorithm

This subsection presents the algorithm that generates the output for the assessment. The flowchart of the procedures is summarized in the figure 5.1.

5.2.1.1 Data gathering

The major part of the algorithm is based on processing MODIS HDF Product File. The first step of the process is the gathering of required data. This process starts with the specification of the study area. This is done through the envelope (minimum rectangle that includes the area of interest) of the Shapefile provided by the user. These coordinates are used to determine the MODIS Tiles that contain the study area. If the coordinates are not in MODIS sinusoidal projection, the envelope is first projected to this projection. For the projection the following formula is used:

Defining (x, y) as the East and North coordinate in meters of a point in the map space, $\rho = 6371007.181m$ as the radius of the sphere of the equilateral sinusoidal projection and (ϕ, λ) its latitude and longitude in degrees, the direct formulas is:

$$x = \rho . \cos(\phi) . \lambda . \frac{\pi}{180} \tag{5.1}$$

$$y = \rho . \phi . \lambda . \frac{\pi}{180} \tag{5.2}$$

The new coordinates in meter are then used to calculate the indexes of the tiles (namely the horizontal and vertical coordinates of tiles in MODIS tiling system (figure 5.2).

$$h = int\left(\frac{x}{t}\right) + 18 \tag{5.3}$$

$$v = 8 - int\left(\frac{y}{t}\right) \tag{5.4}$$

t= 1111950 m is the size of the grid defining the tiles.

Once the tile numbers are determined, the file to download is searched using the following process according to MODIS product name convention.

5.2.1.2 File Naming Convention

The MODIS Product HDF (Hierarchical Data Format) file will always have one of the three following standardized filenames. The prefix MOD is reserved for files containing data collected from the Terra (AM overpass) platform, MYD is reserved for files containing data collected from the Aqua (PM overpass) platform and MCD is used for data derived from both previous products. The file naming convention is common to all Level 3 MODIS Land products: and is explained as follow.

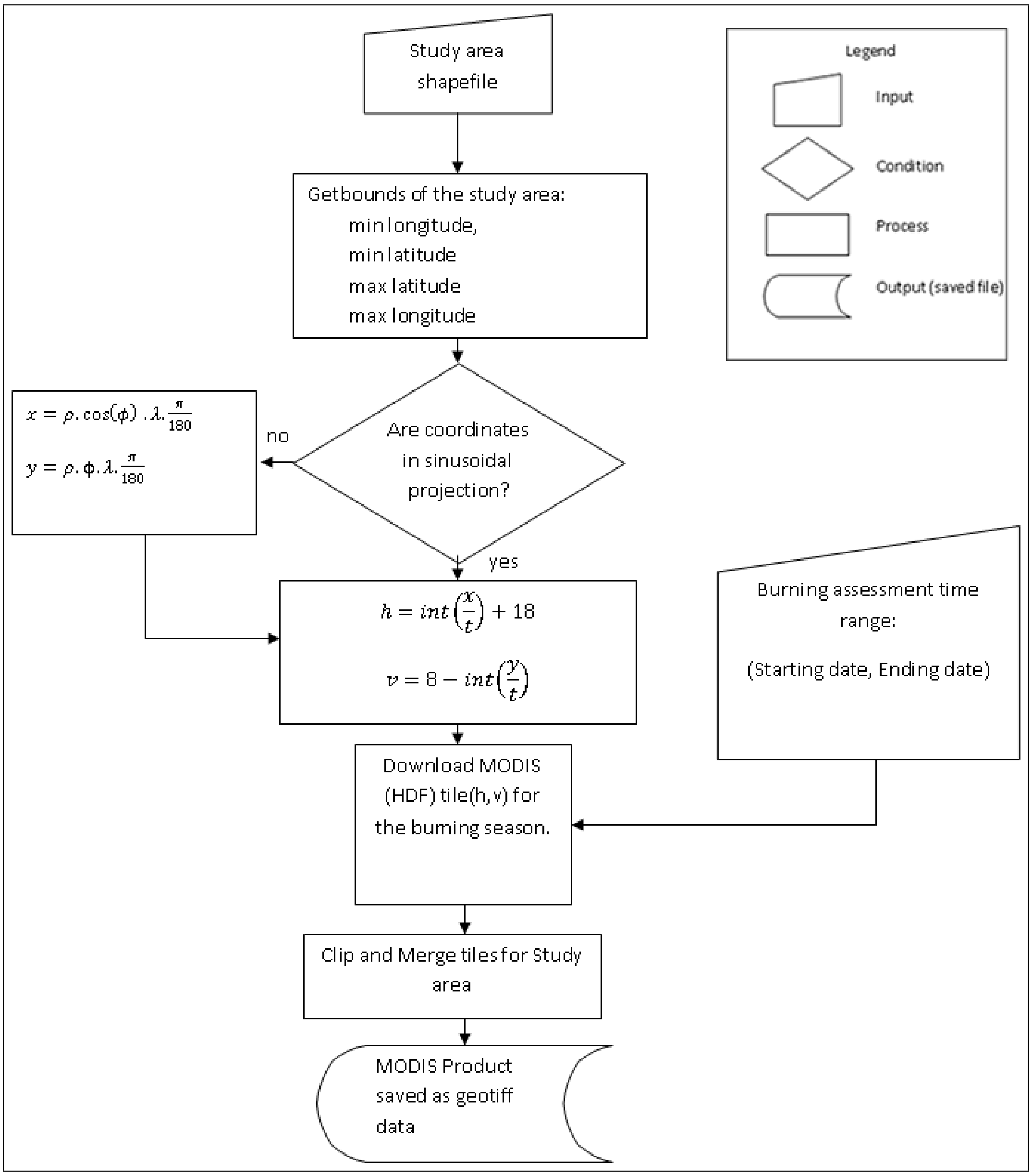


Figure 5.1: Flowchart for HDF data downloading and conversion within SDSS FIMAT

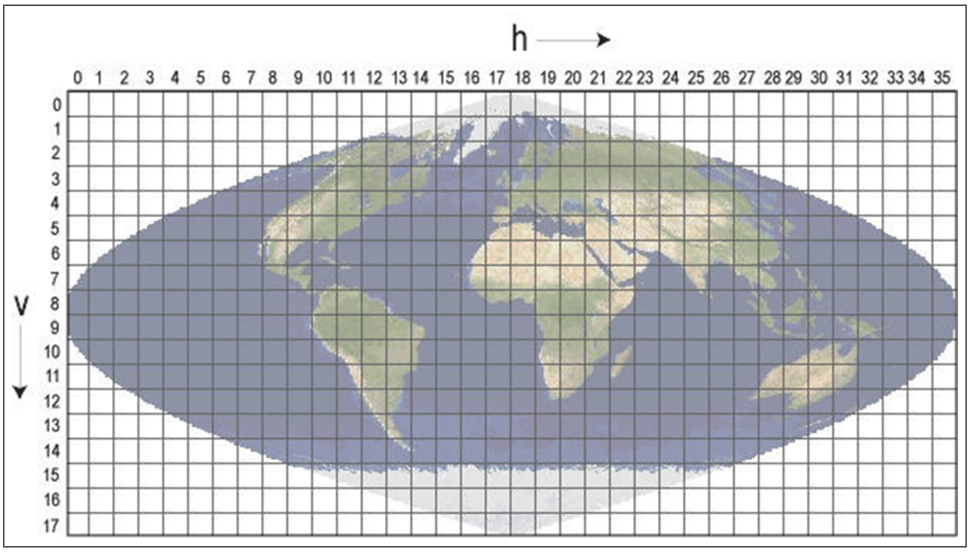


Figure 5.2: MODIS sinusoidal tiling system (Source: MODIS WEB)

- **MOD09A1 - Product Short Name**
- **.A2006001 - Julian Date of Acquisition (A-YYYYDDD)**
- **.h08v05 - Tile Identifier (horizontalXXverticalYY)**
- **.005 - Collection Version**
- **.2006012234567 - Julian Date of Production (YYYYDDDHHMMSS)**
- **.hdf - Data Format (HDF-EOS)**

The files are located in the remote server of NASA which has the following naming pattern: "ftp://e4ftl01u.ecs.nasa.gov/"+Platform+"/"+MODISProduct+ "."+version+"/"+ fileYear + "." + fileMonth + "." + fileDay + "/" (See figure 5.3)

A one table database of all MODIS products characteristics is created. This database contains information such as the short name, the description, the spatial resolution, the temporal resolution. This table is used to specify the description of the MODIS product to download. The time resolution along with the starting investigation and ending investigation date (converted in Julian calendar system) and collection version are used to define the prefixes of the filenames to generate. First the filenames are searched locally in the data folder of the project using regular expression matching. If there are no such files, the files are search out and automatically downloaded via FTP from MODIS server and saved locally in the data folder of the project. For example, for burned area products of 18th March 2006 of Benin (0.7°: 3.8°, 6.2°: 12.4°), the tiles are h18v07 and h18v9 respectively for the north Benin and the South Benin; as the file is monthly, the single file of March (starting at 60th day of the year) is needed for each tile. That results in MCD45A1.A2006060.h18v07.005 and MCD45A1.A2006060.h18v08.005 as prefix. These files MCD45A1.A2006060.h18v07.005* and MCD45A1.A2006060.h18v08.005* are looked up in the local archive and then, if unsuccessful, from ftp://e4ftl01u.ecs.nasa.gov/MOTA/MCD45A1.005/2006.03.01/

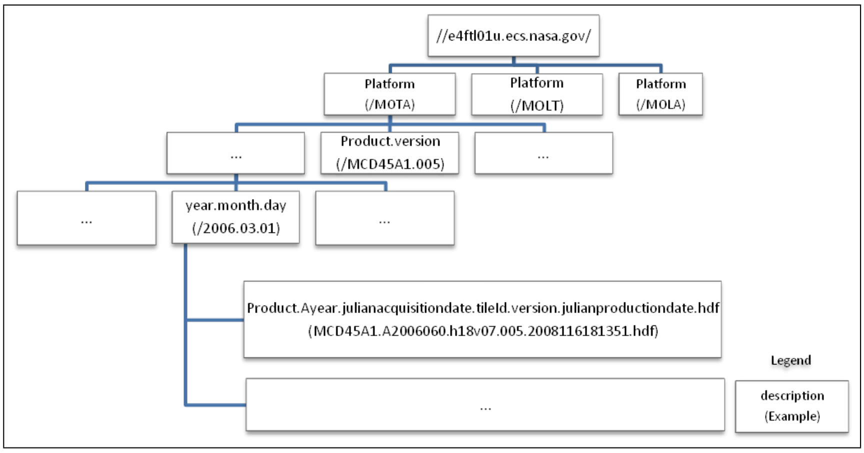


Figure 5.3: MODIS ftp server (ftp://e4ftl01u.ecs.nasa.gov/) file archive structure

The same process is used for any auxiliary MODIS data such as NDVI and Reflectance. Then, the calculation process begins.

5.2.1.3 Calculation process

Pixel burning frequency For each pixel in the area of interest, the number of fire occurrences during the season (Figure 5.4) is extracted from the monthly burned area files and put in another raster file that is called burning frequencies raster for the season. This is done by counting the number of times the pixel appears as burned in each image related to the time period. The Burned Areas product has an overlap of 8 days between consecutive months. This overlap is removed so that those pixels are not used twice.

Pixel first burning day and the following pixel burning The first burning events are derived from each monthly burned area file and merged in on file (see figure 5.4). The same process is used for each pixel, to generate the second and more times burning event until the maximum of fire frequency (maxcount) is reached for the season. A raster file is created as output for each process. This information coupled with the frequency is used to characterize the regime of fire occurrence.

Burning area fraction computing Here the ratio of the total area of interest burnt is calculated by counting the burnt pixels and total pixels. A histogram of the resulting raster is generated and saved as a table of the project. From this table, a chart is generated as well. Thus, the ratios of the total area that burnt once, twice, three times and onwards are obtained. The area of interest is obtained by rasterizing the geometries of the features that meet the query criteria specified by the user during the assessment settings.

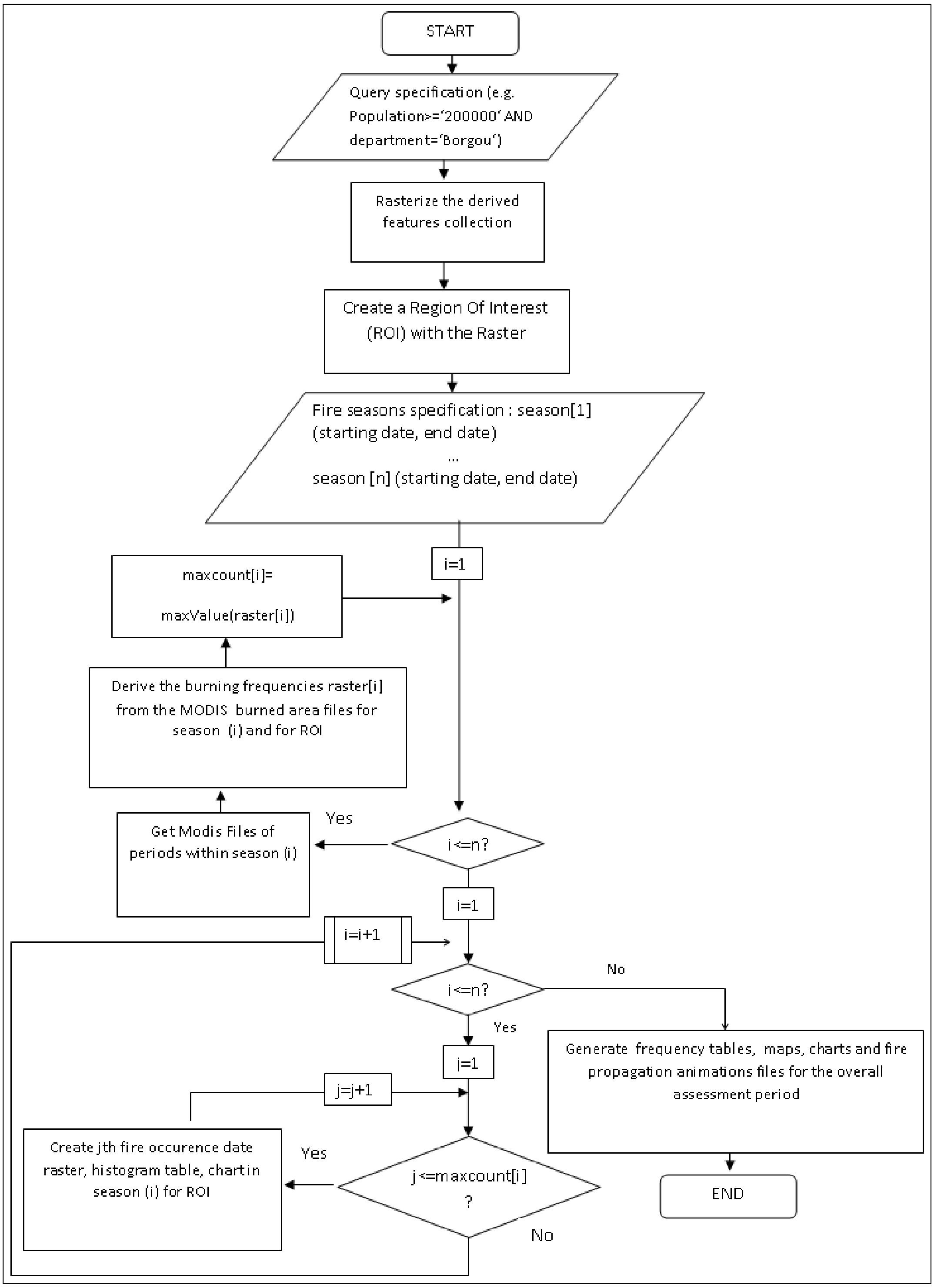


Figure 5.4: Flowchart for the assessment process: calculation of burned area and burning frequencies statistics, creation of maps, charts and animations

Correspondence Analysis . FIMAT is supposed to be used to relate fire information to other features image of the study area. That is, it should allow the user perform correspondence analysis. Therefore, FIMAT allows Correspondence Analysis of couple of images. For two bands of image having common bounds, an Correspondence analysis can be done. Correspondence analysis aims to visualize relations between two sets of categorical datasets by reducing the dimensionality of the data matrix of this dataset while keeping the maximum of information. It is done on a two-way contingency table or the categories of the two data set(Benzérci, 1973). The algorithm is illustrated as follows:

1. Read and assign the vector of value of bandX of image 1 to A
2. Read and assign the vector of value of bandY of image 2 to B
3. Create the contingency table P of row categories of A and column categories of B;
4. Get the row and column marginal totals of P into r and c Let the D_r and D_c be the diagonal matrices of these vectors.
5. Calculate the matrix of standardized residuals: S $= D_r^{\frac{-1}{2}} \left(P - rc^T\right) D_c^{\frac{-1}{2}}$
6. Solve the singular-value decomposition equation to get the eigenvalues and eigenvectors U and V relative to r (row) categories and c categories respectively: $S = UD_\alpha V^T > where \;\; U^T U = V^T V = I$ Where D_α is the diagonal matrix containing the eigenvalues.
7. Calculate the principal coordinates of rows: $F = D_r^{\frac{-1}{2}} UD_\alpha$
8. Calculate the principal coordinates of columns: $G = D_c^{\frac{-1}{2}} VD_\alpha$
9. Get the standard coordinates of rows: $X = D_r^{\frac{-1}{2}} U$
10. Get the Standard coordinates of columns: $Y = D_c^{\frac{-1}{2}} V$
11. calculate the Inertia $=\phi^2 = \sum_{i=1}^{I} \sum_{j=1}^{J} \frac{(p_{ij} - r_i c_j)^2}{r_i c_j}$

The image data reading process is performed using the package Geotools then the matrix operations are implemented using the Java package Apache Commons Math. Commons Math is a library of “lightweight, self-contained mathematics and statistics components addressing the most common problems not available in the Java programming language or Commons Lang”. http://commons.apache.org/math/ .

5.2.2 Java programming language

Java is a programming language whose use is increasing, gaining importance among the software developer community (Murphy et al., 2006). After Oracle’s www.java.com/en/about Web site, more than 6.5 million software developers are using Java. This incentive to use Java is due to its interesting features.

5.2.2.1 Platform Independence

Java compilers produce byte code instruction for the Java Virtual Machine (JVM). This code is no native object code for a particular platform. So it can be interpreted on virtually any platform.

5.2.2.2 Web browser and web services friendly

Java programs can run within a Web browser and Web services.

5.2.2.3 Object orientation

Java is a pure Object-Oriented language. This means that everything in a Java program is an Object. All Objects derive from Java Object class. An Object stores data, but operations can also be performed on it by making requests. In theory, any conceptual component in the problem under resolution can be represented as an Object in a program. A program is a set of Objects interacting between each over by sending messages. Each Object has attributes which can be other Objects. For instance a map is an object. A map has a scale, one or more layers objects. The layers can be of raster type of vector type. By writing a Java program, this entity can be represented in the same manner in Java see an example of conceptualization in chapter 5. The present dissertation does not intend to dive into these features of Java since that is not the principal aim of the present dissertation.

5.2.2.4 Familiar C++-like Syntax

Java programming language shares many features with C++. In fact, syntaxes, variables type, operators, control structures are similar. Understanding and Converting a C++ snippet code into Java is simple for a Java programmer.

Some components of the Graphical User Interface of this Fire Management Tool are designed using, packages, design patterns and adaptation of snippets of code freely available on Internet.

- for the Charting module JFreeChart package (http://www.jfree.org/jfreechart/) is used.
- Geotools package (http://www.geotools.org/) is mainly used for geographic mapping module
- The spreadsheet Module is adapted from SharpTools (http://sharptools.sourceforge.net) snippets
- Java HDF packages (www.hdfgroup.org/hdf-java-html/)are used in processing HDF files.
- Pdfs are written and browsed using jpedal and iText (http://itextpdf.com/).
- many apache packages are used in processing (http://www.apache.org/).

- The Look and feel and windowing system take advantages from the infonode Packages (http://www.infonode.net/).

Most of these packages are available at SourceForge.net project web site (http://sourceforge.net/projects/). SourceForge.net is the world's largest open source software development web site. It hosts free services (packages and documentation hosting, sharing, networking, forums and other resources) that help people build interesting application and share it with a global audience.

Fire Management Tool (FIMAT) is designed to help fire management officers in their tasks of vegetation fire assessment. With this tool, the user can get information on burned area and recent fires. FIMAT can generate fire frequencies for a range of time period. These frequencies are presented as a customizable map. The statistics such as the proportion of the burned areas can also be represented in customizable charts.

5.2.3 Structure of the application FIMAT

SDSS FIMAT is based on the concept of Model-View-Controller (Figure 5.5). FIMAT application may contain many project elements.

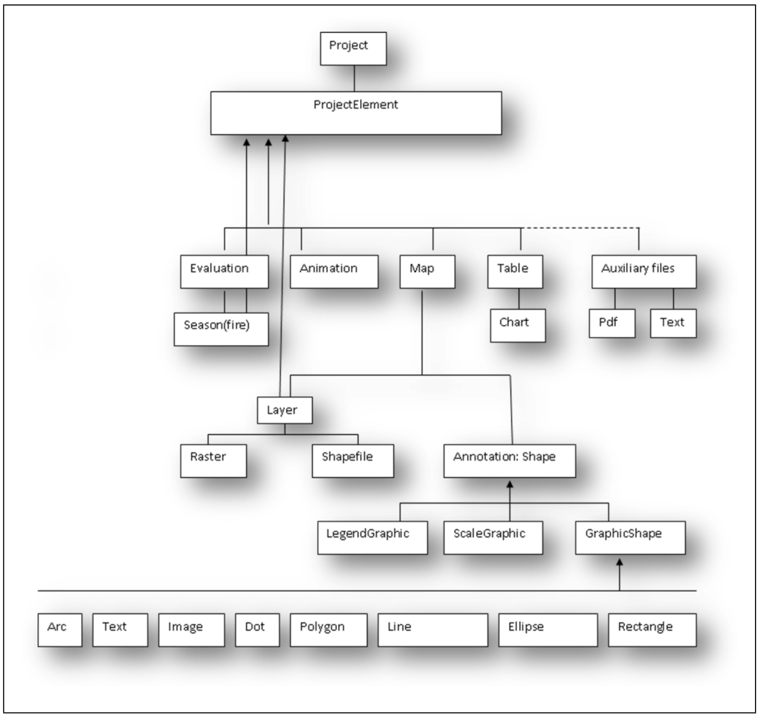


Figure 5.5: Structure of a Project Model within FIMAT

The model is composed of various elements organized in the following hierarchy: The project is the root of the model. A project contains assessments, maps, animations and charts. An evaluation generates results in the form of tables, charts, geographic layers and animations. A map is composed of geographic layers and annotations. The geographic layers are created from vector files (shapefile) and images (geotiff, worldimage file). These data files are accompanied by their OpenGIS Styled Layer Descriptor (SLD) representation file. It is a standard defined for OpenGIS to allow user-defined symbolization and coloring of geographic feature (http://www.opengeospatial.org/ogc/glossary/f) and coverage (http://www.opengeospatial.org/ogc/glossary/c) data. This SLD file is automatically generated and modified through the symbolization process. This data model design enables the serialization of the elements of project. Thus, the user can save the whole project as an entity in XML format for further processes.

Views are windows which allow viewing of items. The views contain tool bars specially dedicated to the handling of each type of model element in the view. Thus a map view contains tools for zooming, panning, and annotation. The views of PDF have buttons to navigate from one page to another, the view animation contains buttons to start or stop an animation. The maps are viewed and edited in a map view. Charts are also displayed in chart views.

The controller is the part of the internal module that lets the user modify the model according to the manipulations he makes through the views. It updates the views in response to changes in the model. It also includes all the calculation and process routines of the software.

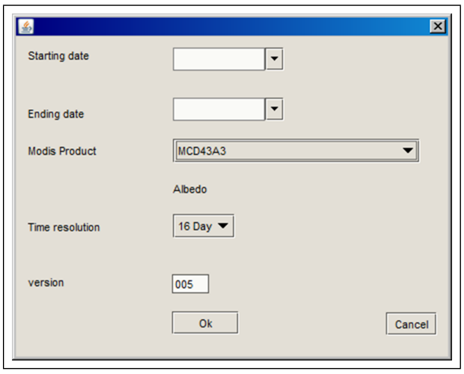
The controller contains several modules:

- The data manager. The data are collected as files locally on the user's disk. Two types of source files can be distinguished: the files that are provided explicitly by the user and that are loaded explicitly by the user at runtime and the automatically downloaded files during the process of evaluation. These files are gathered by the program from NASA Server according to the parameters (date, and location) provided by the user during the running of the program. These are especially MODIS HDF files. Several types are to be distinguished. Burned areas files, reflectance files , vegetation index files. FIMAT holds a HSQL data base of the characteristics of all MODIS products. These properties are presented in a Dialog (Figure 5.2.3) where the user can easily specify the properties of the MODIS product he needs through queries. The files are also downloaded from RapidResponse System for active fires.

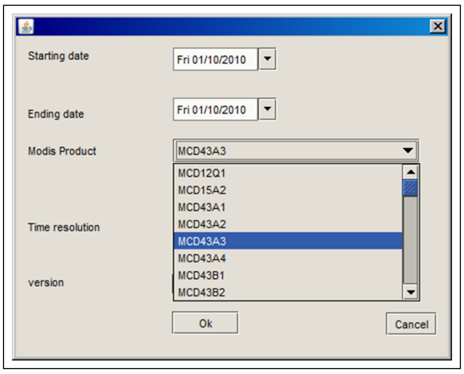
- The data processors. These modules generate statistics, charts and graphs. These processors use the data collected and perform various tasks related to the assessment. The fire statistics are calculated from MODIS files and tasks such as queries are performed to generate results in text, tables, charts, animations and geotiff images form.

- The mapper is used to show different layers of information generated for the assessment. These layers can be geotiff images, world file images or shape file. Any MODIS product in HDF format can also be just added to the map. The mapper is customizable through the embedded SLD editor. Different graphic shapes can be added as well.

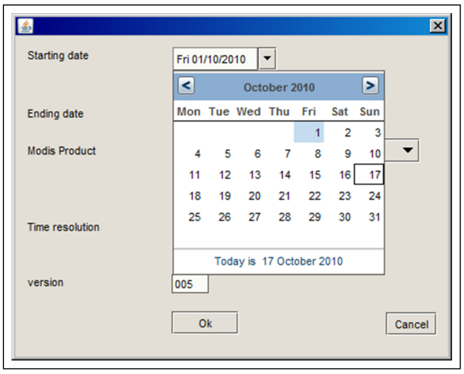
- The reports module presents the charts generated.



(a) MODIS product download Dialog



(b) Choosing MODIS product



(c) Choosing period in which the data are required

Figure 5.6: MODIS products download Dialog in FIMAT

5.2.4 FIMAT file formats

FIMAT use “fmt” (XML) project format to save the user project. This file contains the serialization of all objects in the project. The user gets back his data by opening this file.

5.2.5 FIMAT windows and views

As you work with FIMAT, a number of different windows and dialog boxes will appear on your screen. These allow you to manipulate and analyze your project. On starting the program the application window shows up. This is a simple window with a menu bar (1), a tools bar (2) and a main content pane (3). Buttons and menu items are used to open an existing project or create a new one.

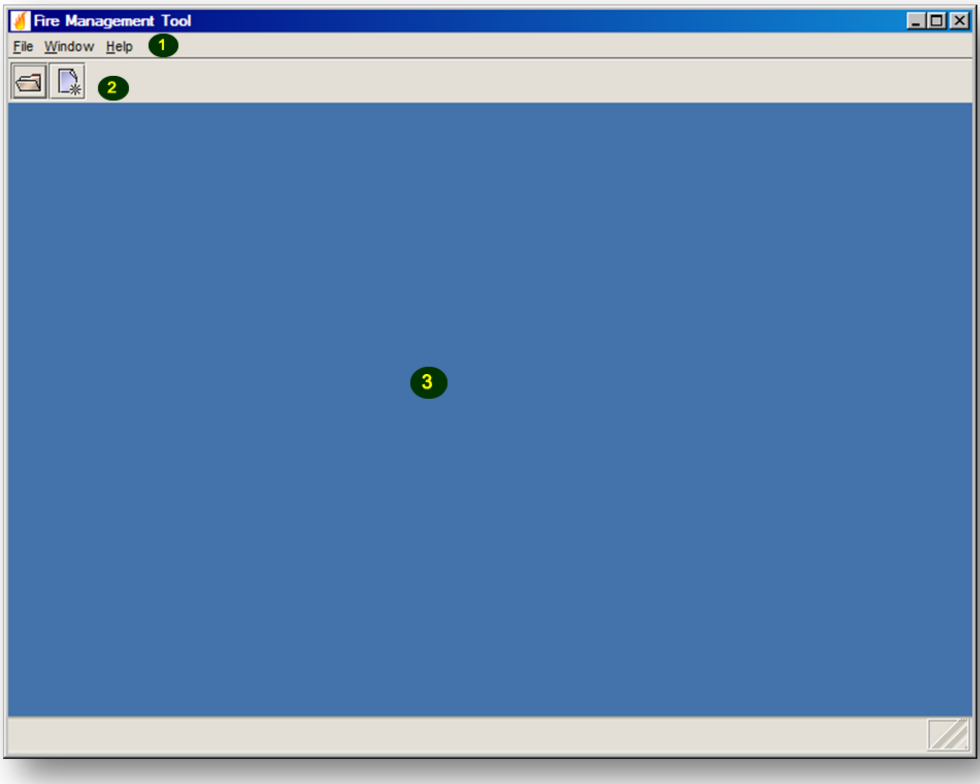


Figure 5.7: Application Window of SDSS FIMAT: menu bar (1), tools bar (2) and main content pane (3)

5.2.6 Menus in the windows and views

On loading an existing or creating a new project, the main window of that project is shown. The project window encompasses a menu bar and four views.

- The Project File Explorer - this is where all or part of a project files are displayed (1)
- The Hierarchy of the project - displays the project elements tree (2)
- The Console - displays information on the current process. (3)
- The main View - this is where map views, report views, chart views are displayed (4)

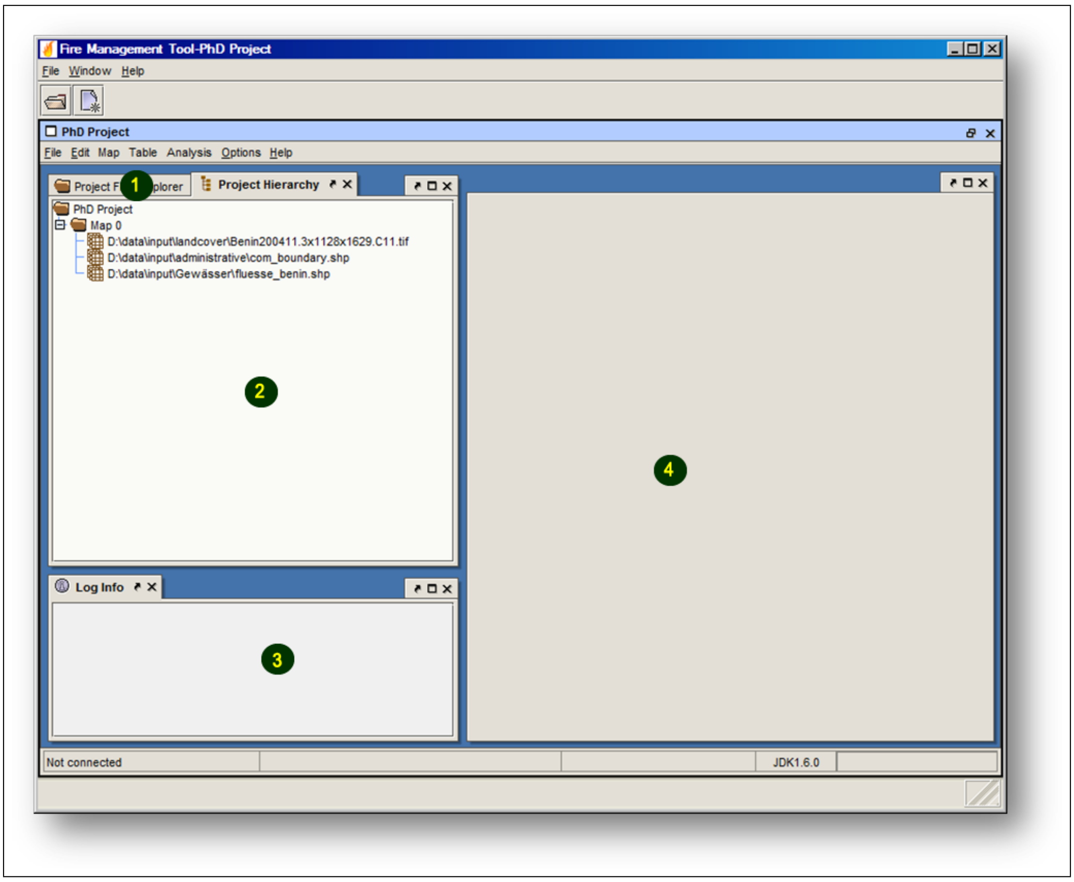


Figure 5.8: A Project View of SDSS FIMAT: (1) Project File Explorer, (2) Hierarchy of the project, (3) Console, (4) Main View

The menu bar contains the following functions: File, Edition, Map, Chart, Analysis and Help. The Views are File Explorer, Project Hierarchy Explorer, Log View and the main Project View. The File Explorer presents all the files inside the project. The user can add external files as well. The Project Hierarchy Explorer is used to show the different elements in a Project. These include Maps, Charts, Animations. The log view shows the runtime information. The main Project View (Figure 5.9) is where other Views are dynamically displayed. These dynamical views are reports of the results of processes. They includes maps (1), tables (2),

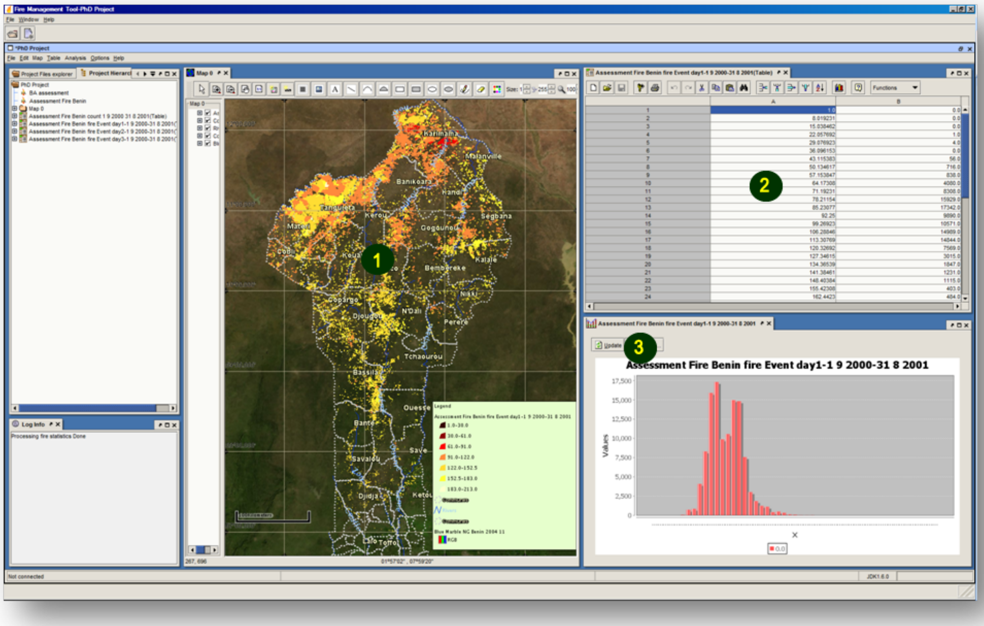


Figure 5.9: Different views of the SDSS FIMAT: (1) Map View, (2) Table View, (3) Chart View

charts (3) and others (animations, texts, pdfs). The arrangements of those views can be customized by the user (Figure 5.10).

The FIMAT Project Window has its own internal menus, which provide access to interactive display and analysis functions. These menus appear as a standard menu bar at the top of each Project Window. Menu items can be selected from it the same way it is done from any other Window menu. At the bottom of the Project View, the Project View Status bar (Figure 5.11) is found. It gives information on the current task (1) running and the progress (3) thereof. There is also displayed the Java version (2) of the system.

5.2.7 Dialogs

Dialogs are shown to help the user to specify parameters for process. There are triggered by menu item or on mouse click or moves; main dialogs will be presented in detail in each process where they are used.

5.2.8 Presentation of fire assessment process

The main modules involved in fire assessment are the calculation of fire statistics and generating fire timing information. The results of those process are in various forms. Mainly in tabulated data, raster images, charts and animations. In subsequent section, the processes are described.

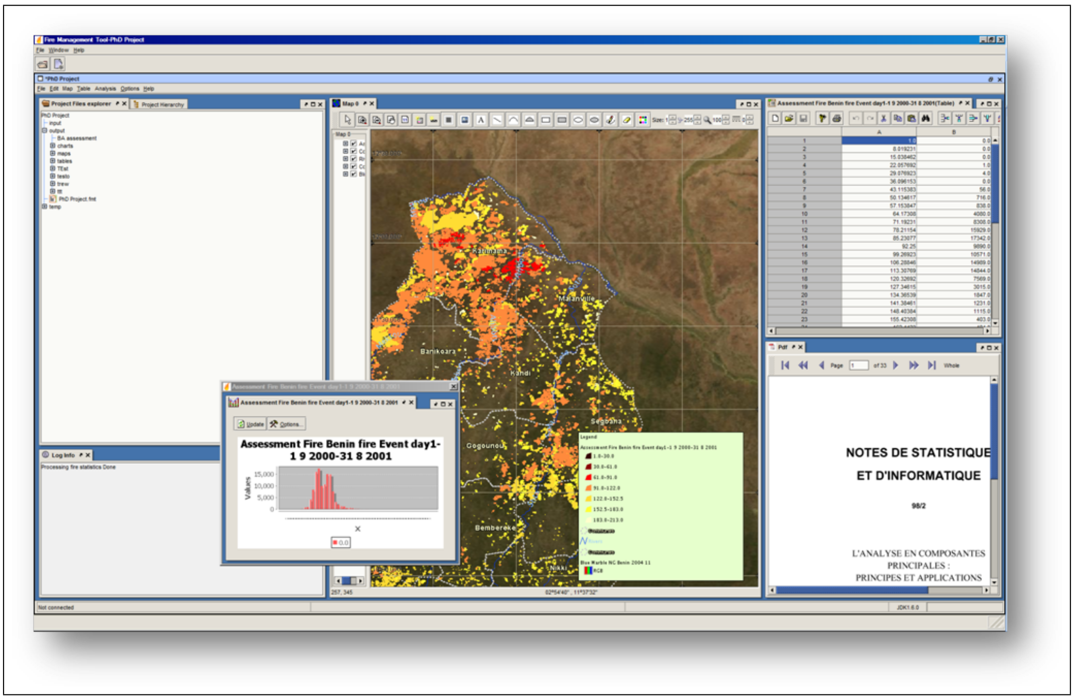


Figure 5.10: Views arrangement of SDSS FIMAT

Figure 5.11: Status Bar of the Project View of SDSS FIMAT: (1) current task , (2) Java version, (3) progress

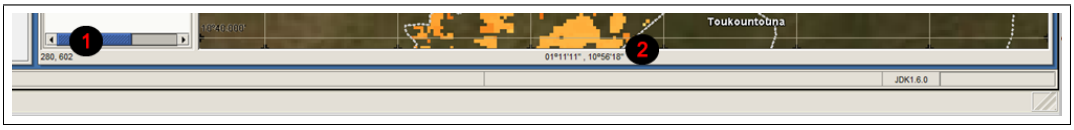


Figure 5.12: Map Editor Status Bar of FIMAT: (1) current position of the Mouse in screen coordinate, (2) current position of the Mouse in map coordinates

5.2.9 Generating Maps, Charts and reports

5.2.9.1 Mapping

Mapping is performed in the Map Editor of FIMAT. The Map Editor is a View made up with Map edition tool bar, the map Layer Controller Tree and the Map Canvas. At the bottom of the Map Editor, the status bar gives information on the current position of the Mouse in screen coordinates and map coordinates (Figure 5.12).

The Map Edition Tool bar. The Map Edition Tool Bar contains the Map viewing tools and Map decoration tools. The Map viewing tools are zooming and panning buttons that are used to control the scale of the Map. The annotations buttons enable adding and controlling annotations such as map legend, map scale bar, the north arrow, external graphics, and others graphics to the Map.

The Map Canvas The Map Canvas (Figure 5.13) is a panel that shows the actual map. It shows the rendered map image as defined by the layers and their representation along with decoration. A graticule and a grid can be added by the user on top of the map. All map is rendered in the geographic coordinate referencing system. That is, every layer is automatically converted to the default Geographic referencing system. Any shapefile, geotiff, world image of EOS HDF file can be drawn upon the Canvas to be included in the map. The location of an annotation of the canvas is defined by drag and drop mechanism. Zooming and Panning are carried out by the mouse clicking and moving according to the toggle buttons selected on the map editor tool bar. The rendered image can be exported in different types of image format including png, jpeg, tif, bmp.

The Map Layers Control Tree This is a tree of the loaded layers of the map. It shows the map layer name, the layer icon, the layer type and the representation rules of each layer. The overlay order, the visibility and the style of the layers on the Map canvas are controlled with the layers control tree. Layer can be added to the current map by drag-and-drop process on the Map Layers control tree.

a) Symbology of a vector layer

   The vector layer style editor is used to customize the presentation of Polygon, Line and Point layers. The user defines the rules for the presentation. These rules include the symbol to use, the colour, the thickness, the style of the stroke and so one (Figure 5.15).

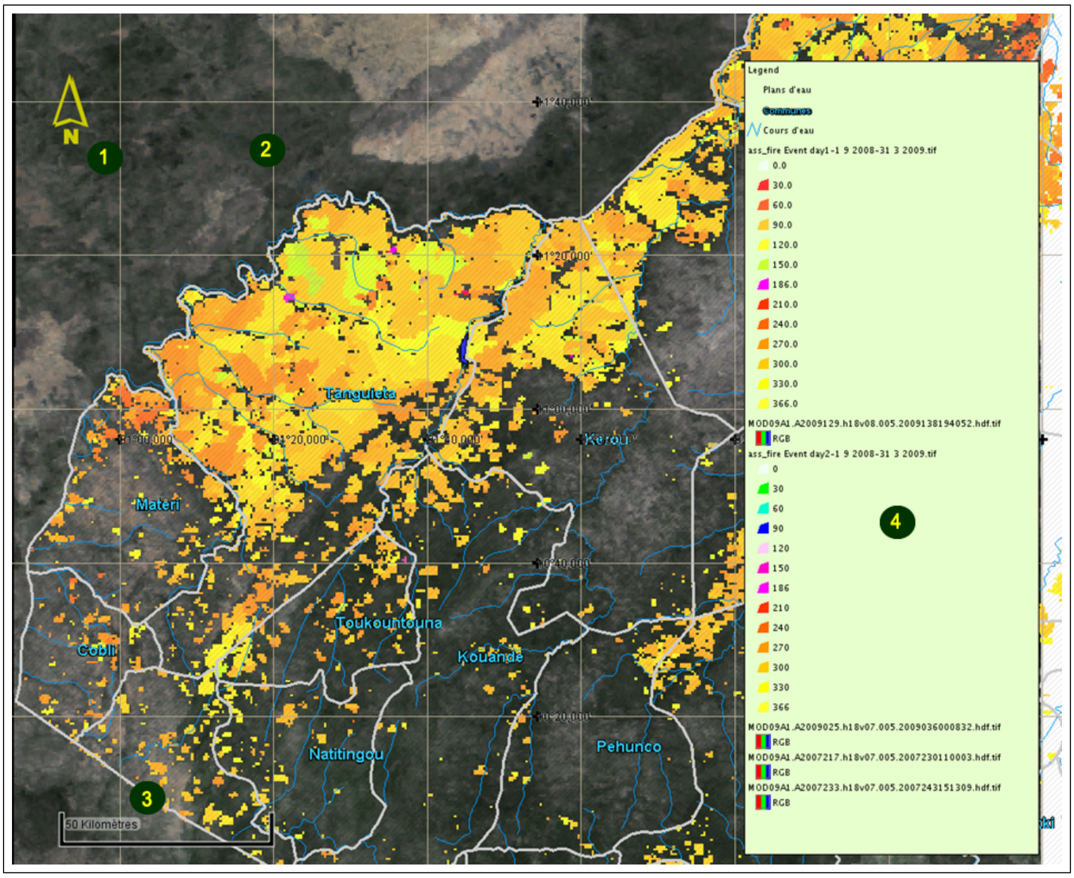


Figure 5.13: Map Canvas of FIMAT: (1) north arrow, (2) graticule, (3) map scale bar, (4) map legend

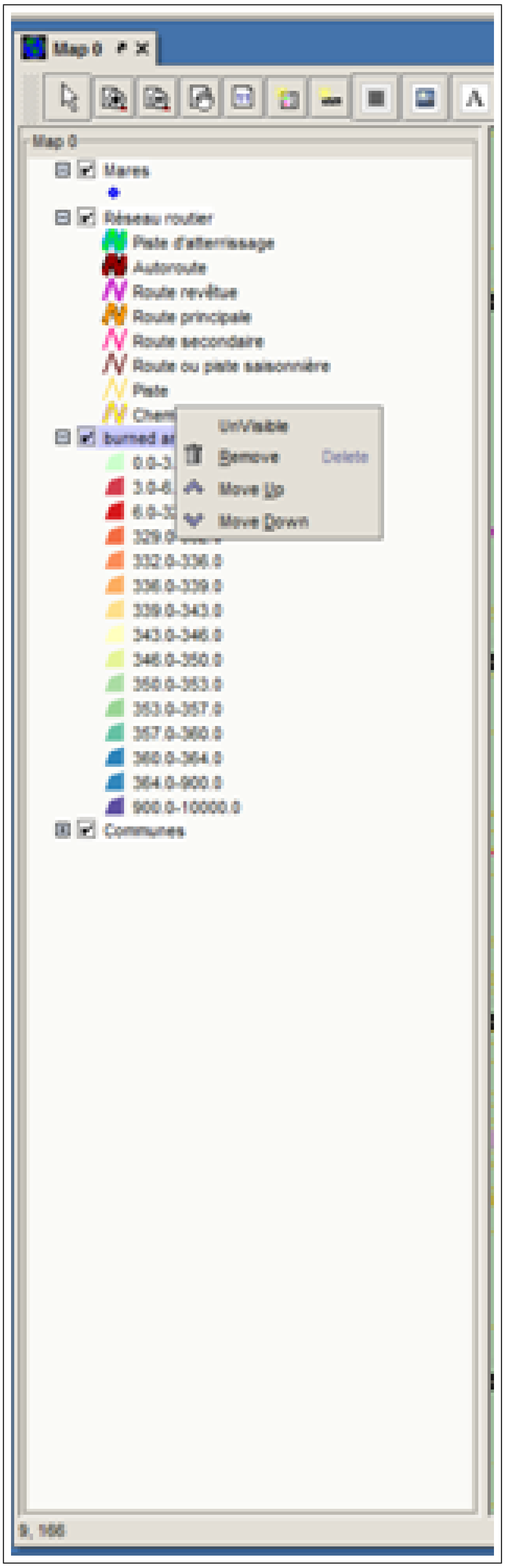


Figure 5.14: Map Layers control tree of SDSS FIMAT

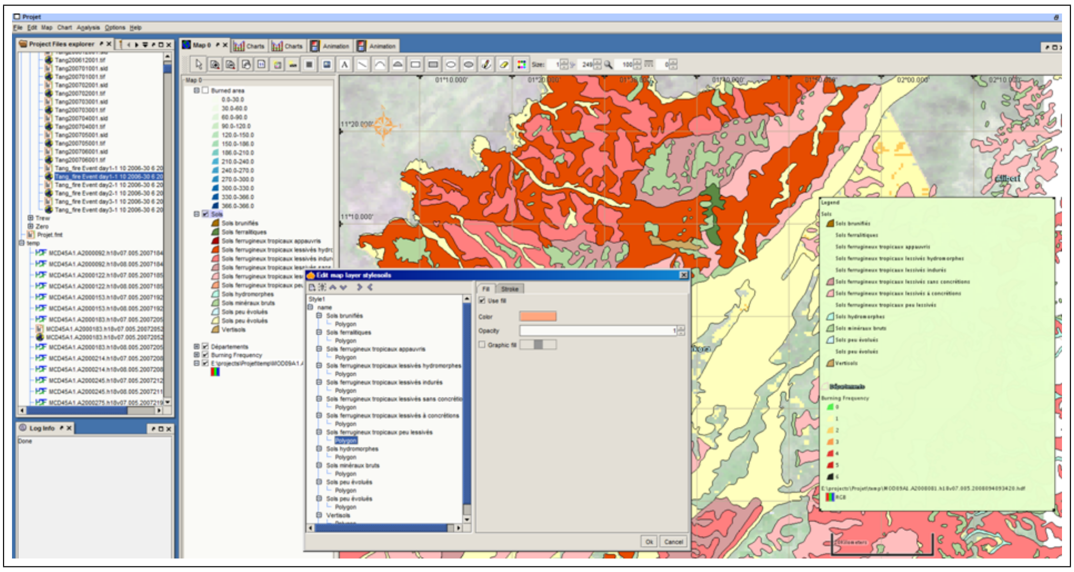


Figure 5.15: Vector Layer Representation Editor of SDSS FIMAT

b) Symbology of a a raster Image

   When the raster image contains 3 or more bands, the user can choose the combination of 3 bands to affect to the RGB channel. For example a true colour image can be obtained for a MODIS reflectance product by combining the 1st, 4th and 3rd bands (Figure 5.16).

   Stretched band editor uses just levels of gray to represent the value of one band. Any layer of an image can be represented as colour map styled image. There are three types of colormap: values, ramps, and intervals. With values colour map, each value of the image is affected a colour while for ramps and intervals, the data are classified into intervals prior to the assignment of colours to those intervals. The difference between colour ramp and colour intervals is that, for intervals colour map, one colour is assigned to each class of data where as colours are interpolate within classes for ramps map colour. FIMAT build intervals with three methods of classification: quantiles, natural breaks, and equals distance. Quantiles are used as breaks in quantile method thus the classes are of equal numbers. For equals distance the whole range of data is divided into equidistant intervals. The natural breaks method uses Jenks method (Jenks, 1967) to create the intervals. The data are partitioned so that the variation within the groups is minimal (Figure 5.17).

c) Annotations

   Annotations are graphics (shape) that decorate the map. They are of two types. The simple geometric shapes such as rectangles, icons, ellipses, line and text are used to annotate maps. The annotations related to geographic layers are scale bar and the legend. These items can be edited by the user. Thus,

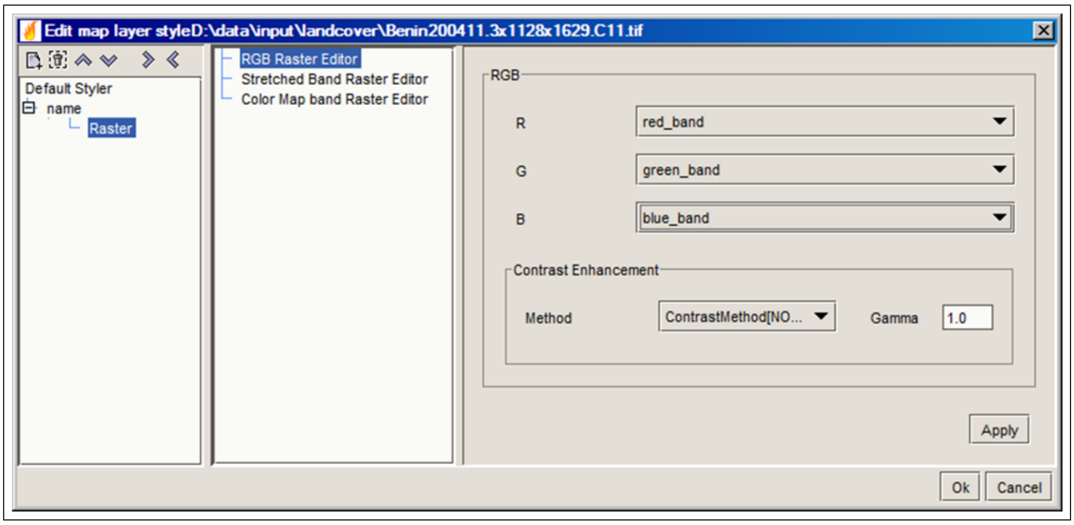


Figure 5.16: RGB Image Representation Editor of SDSS FIMAT

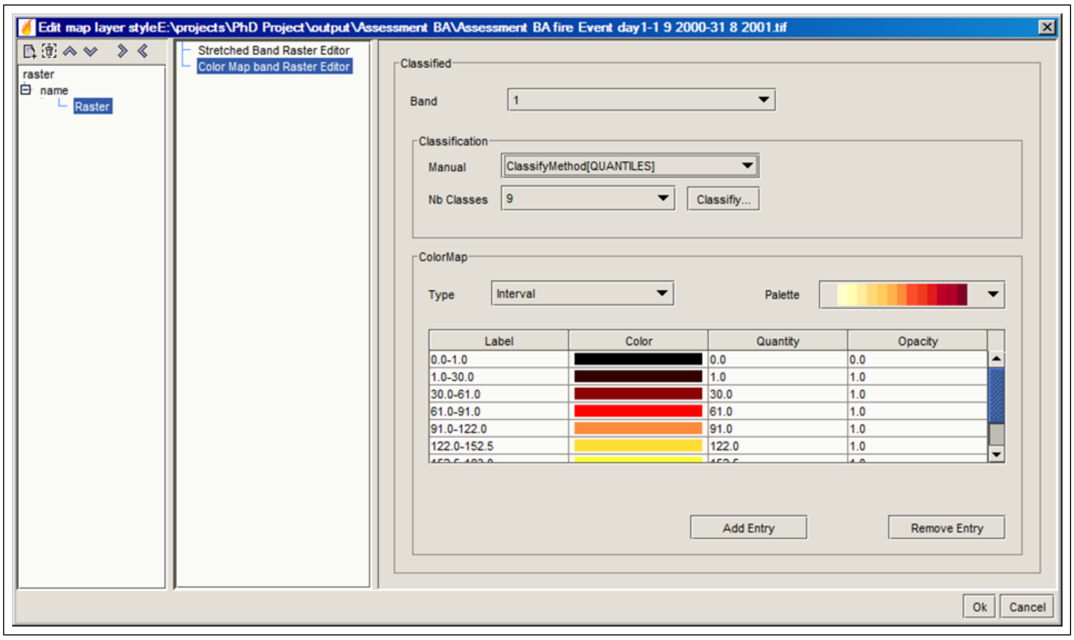


Figure 5.17: SLD Editor of SDSS FIMAT

attributes such as line thickness, colour, type of contours, text attributes are customizable.

d) Charts

Excel like charts are generated during the assessment. These charts can be displayed and modified using the Chart Editor. They are built on the top JFreeChart Library. Different features of the chart including the Titles, the legend, the Plot and Axis can be interactively customized.

e) Animation

The assessment process involves the creation of animations. Animations are sequence of daily snapshots of the burning area in time. For instance to create an animation from a burned area files, a query is used to get only the pixels that burn before or on each date of the assessment period. One raster image is created for each day. Animation images related to an Assessment are saved in a subdirectory of this Assessment. Each image is added to the current map by a Java thread using the Java Timer object, then a snapshot of the map is created, numbered and saved. These final images will be the frames of the animation. An Animation object which contains the settings of the animation (the directory of the images files, the number of frame per second, the size of the animation) is created and added as a child to the Assessment object. This allows the user to view the animation later when he opens the project. Animations are viewed using Animation View. An animation can be started, stopped and resumed using the Animation View tool bar buttons. The animations can be exported as animated gif and used for instance in a PowerPoint presentation.

5.2.10 Usage of FIMAT

FIMAT is started by running the executable jar thereof. After running the user will get the main Application Window. Next he creates a new project or opens an existing project.

5.2.10.1 Creating a new project

File>New>New Project A New Project dialog will show up.

In this dialog the user gives the name of the project, the path where the project will be saved and he specifies a shapefile that represents his study area. He clicks ok. Then he gets the project window.

5.2.11 Presentation of the Project Window

5.2.11.1 Making an assessment

A new assessment is started with the menu *Analysis>Make and assessment* An Assessment Settings Dialog appears.

A title to the project is given in the title field and the comboboxes are used to create a Query in the Query Text Fields. Next seasons of year under investigation

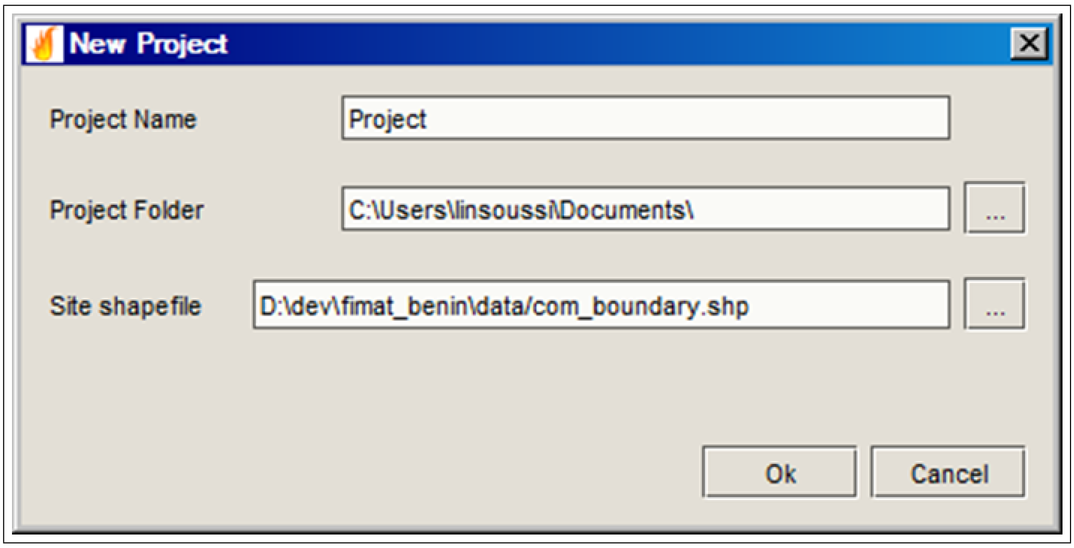


Figure 5.18: New Project Dialog of SDSS FIMAT

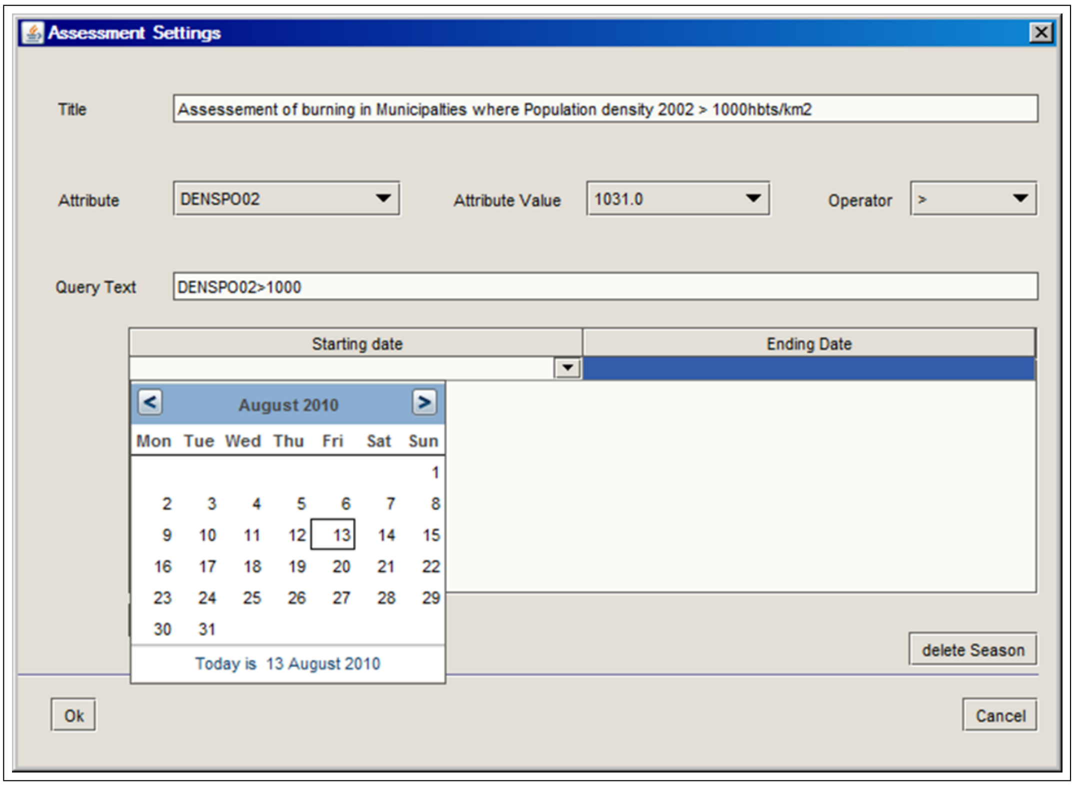


Figure 5.19: Assessment Setting Dialog of SDSS FIMAT

should be added. On click of the Ok button, the Analysis processes start. The Outputs are saved in the project output folder and the downloaded files are kept in the project temp folder. After the completion of the Assessment task, the user can display the various images, charts, animation generated in the Project Main View using the corresponding views. Default representations are provided for Map Layer in form of Styled Layer Descriptor file that are saved along with the Map Layer. On loading the Layer in a Map, the user can modify the representation through the SLDEditor.

5.2.11.2 Creating a Map

Select *Map>New Map* Use the displayed Input Box to give the title of the Map or keep the default. The Map View displays a new map with the site shape file included. A grids Line layer (Graticule) is drawn on top of the whole Map with label in geographic coordinates. At the bottom of the Map canvas are displayed the coordinates of the Mouse Pointer in map and in view coordinates. Use the Zooming Tools to Resize the Map. Drag any shape file, geotiff file, EOS HDF file, or world image file on the Map Canvas. By adding an HDF file, a Bands List dialog appears allowing you to select the Scientific Datasets you want to include as band of the layer. The Layer is then rendered on the Map. When the image contains 3 or more bands, the first three bands are affected to the RGB channel respectively. You can change the channels selection according to your preferences using the SLDEditor.

5.2.11.3 Changing the representation of a layer

Double click on the layer in the layer control tree. The SLDEditor shows up. The content of dialog depends on the geometry of the Layer.

5.3 Conclusion

This section offers an insight into the development of FIMAT, a Spatial Decision Support System for fire Management using mainly MODIS products. It is a Java program written with various packages developed by Java programmers community. The SDSS includes a data collector data processor, a map editor, a chart editor, an animation creator and various other viewers. The various processors, report generators and the overall Graphical User Interface assist the decision makers in their assessment tasks. Many tasks are automatic, preventing the users from annoying routines related to MODIS data pre-processing like file format conversion, re-projection or using of third party commercial software for mapping. FIMAT will be extended later

- to include features such as automatic meteorological data collection, processing and the use of those meteorological data as input parameters to fire risk assessment.

- to enable plugins architecture: thereby, enabling modularity and easy extension.

- to make it compatible with more image formats.
- to integrate more processing modules and to include more statistics analysis modules.
- to include images processing modules.
- to make it a generic environment modelling tool
- to enhance shapefile digitalizing

The methodology can also be adapted and used for similar studies in other environment fields. In the following chapter, the use of FIMAT to describe fire pattern during 2000 to 2009 in Benin is presented.

Chapter 6

Spatial and temporal distribution of bush fire in Benin from 2000 to 2009

6.1 Introduction

Wildland fire is a key factor in the health and sustainability of global vegetation(International Forest Fire News (IFFN), 2003). Biomass burning contributes as well to inter-annual variations in trace gases such as carbon dioxide, methane, and carbon monoxide. Therefore, the description of the distribution of fires is needed to understand the scale and variation of the impacts of those wildland fires. Since many countries especially the developing ones including Benin do not hold accurate fire inventory data (FAO, 2007a), satellite data have been viewed as a key source of fire information (Justice et al., 1993; Justice and Dowty, 1994; Malingreau and Gregoire, 1996). This interest led to the development of several global fire data sets that are now publicly available to the scientific community. These datasets can be processed with tools like FIMAT and valuable information can be retrieved for environment process study like wildfire assessment. This subsection investigates bush fire dynamics from 2000 to 2009 using FIMAT, MODIS Burnt area products (MCD45A1) and results of field works of local fire management institutions. This section is a kind of FIMAT usage and performance demonstration. MODIS burned area level 3 product is derived from processing of combined MODIS-TERRA and MODIS-AQUA 500m daily land surface reflectance data using directional reflectance (BRDF) model-based change detection approach (Roy et al., 2005). This algorithm determines the dates of burning based on the Julian calendar by locating the occurrence of rapid changes in daily MODIS reflectance time series (see appendix D).

The burnt area product is used to analyze the pattern of bushfire countrywide in Benin. Fire event frequencies at each pixel are extracted from this data. The results of each year are compared and the process of the propagation is described. The events are classified as early and late fire event considering the raining season. The results are mapped.

Objectives

The objective of this section is to show the performance of FIMAT for Benin. The study has three aims. First it aims to know the burning pattern over the period of 2000-2009. Then it tries to investigate relations between burning regime and Land-cover, on the one hand and between burning pattern and rainfall pattern on the other hand.

Data and methods

The data are:

- MODIS data as presented in previous sections (see chapter 4)
- Rainfall data from 2000 to 2007 (Source: SMN-Benin)
- Subset of Global Land Use/land cover data of 2004-2006 for Benin (Bicheron et al. (2008)).
- Socio-economical data from census 2002 (source INSAE (2004)).

The rainfall data are obtained from the national rainfall station. These data cover the period from 2000 to 2007. Actually, the goal of this section was to describe the wild fire distribution pattern in relation to rainfall for the study period, namely the same years as MODIS dataset (from 2000 onwards). Yet, there is no data available for 2008 and 2009. The available daily original datasets are preprocessed and converted to a more convenient format. Monthly and annual sums are generated from them. The data are filtered and only stations with reliable information are retained. These daily data are sum up to monthly and annually data.

The subset of Global Land Use/land cover data of 2004-2006 is got from the ESA web site. The subset of Benin is obtained from the cropping and re-projection of the continent wide (Globcover_V2.2_Africa.zip) dataset. The Globcover land cover product has 300m spatial resolution for the period December 2004 - June 2006. The map projection is a Plate-Carrée (WGS84 geoid). This raster data stores Land cover class code in an integer raster format. The codes and their meaning are presented in table 6.1

Study area

First, the whole country is considered for the overview of the evolution of the burning in space and time. Then we focus on the Pendjari park for the relation between burning characteristics and land cover type. The park belongs to the WAP complex (W-Arli-Pendjari ecosystem), one of the largest group of protected areas in West Africa (CENAGREF, 2006). Pendjari is located in the extreme northwest of the Republic of Benin inside of the department of Atacora (see chapter1).

6.2 Results

6.2.1 Countrywide burning pattern over the period 2000-2009

Bush fires usually occur during the dry season. Countrywide, it burns between last October or early November and May throughout the period of 2000 to 2009

Table 6.1: Land cover class and description (source: Bicheron et al. (2008))

Value	Label
11	Post-flooding or irrigated croplands (or aquatic)
14	Rainfed croplands
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)
32	Mosaic forest (50-70%) / cropland (20-50%)
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)
41	Closed (>40%) broadleaved evergreen and/or semi-deciduous forest (>5m)
42	42 - Open broadleaved evergreen or semi-deciduous forest
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)
130	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)
134	Closed to open (>15%) broadleaved deciduous shrubland (<5m)
140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)
141	Closed (>40%) grassland
143	143 - Open grassland
150	Sparse (<15%) vegetation
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water
170	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water
190	Artificial surfaces and associated areas (Urban areas >50%)
200	Bare areas
210	Water bodies

(Figure B.18 to figure B.26). In Benin, every year 13% to 23% of the country's territory is burned (Table 6.2). Variations are observed in relation of the pattern of rains. In southern part of the country less wildfire are observed. Almost the whole area of Pendjari National Park burns each year. The early fires are generally observed in the Park W and the Pendjari park (Figure B.9).

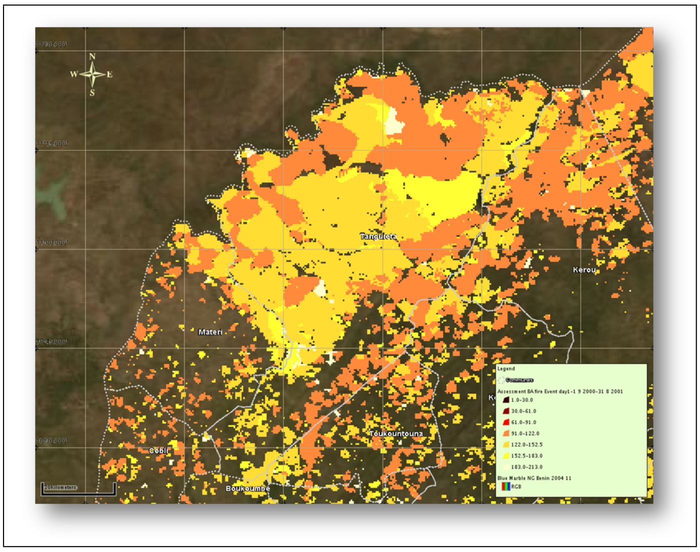
The brown to white colours indicate the approximate day of burning in the month. The bushfires season extends regularly from last October or early November to April, throughout the period of 2000 to 2009 (Figure B.18 to figure B.26). The pattern remains the same: Every year in average 17% of the area is burnt countrywide. In December, most proportion of the country area is burned. The burnt areas are mostly the protected ones.

Table 6.2: Evolution in Pixel count of fire frequency from 2000 to 2009 based on MODIS burned area product (one pixel: 500mx500m)

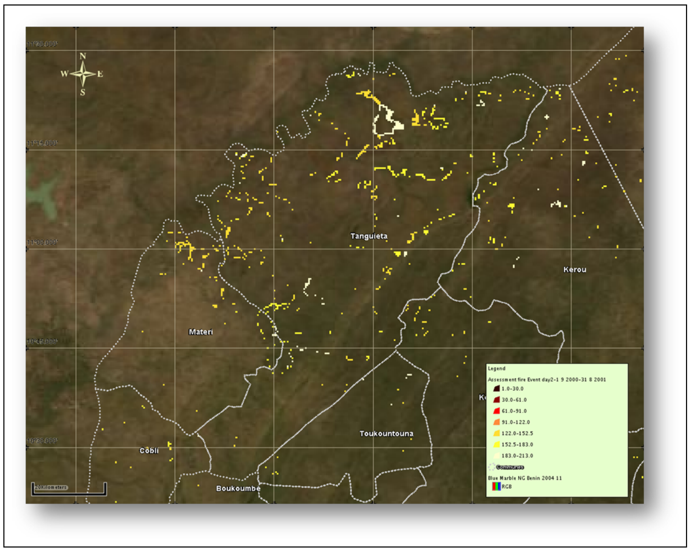
Frequency	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009
0	433382	434645	420468	452593	458937	437786	437355	468705	475433
1	109865	108381	122312	90709	84935	104915	105666	74711	68024
2	1525	1745	1938	1452	901	2044	1738	1346	1313
3	3	4	56	21	2	29	16	13	5
4	0	0	1	0	0	1	0	0	0
burned pixel count	111393	110130	124307	92182	85838	106989	107420	76070	69342
pro-portion of burned area [%]	20	20	23	17	16	20	20	14	13

6.2.2 Temporal frequency distribution of early burned area

Generally, it burns once a year during the dry season but in some areas it could burn twice, three or even four times. In average 2%burn at least twice, independently whether they are protected or not. The high frequencies are mostly observed in the parks (Figure 6.1). Those areas that burn several times are usually found inside national parks and occur often at the fringe of the late burning sites. They are extensions of the late burning areas to the early burned areas. Since 2007, the total burned areas and the frequency of fire events have decreased each year (Table 6.2).



(a) First burning



(b) Second burning

Figure 6.1: Spatial and temporal distribution of bush fires during the season 2000-2001 in Pendjari park: (a) first burning events, (b) second burning events

6.2.3 Fire distribution versus land cover

6.2.3.1 Burned area in Pendjari Park: contribution of the different land cover types

In this subsection, the result of description of burning pattern in relation with land cover is presented. Focus is made on the National Park of Pendjari where the fire frequencies are more important. Figure 6.2 shows that the vegetation in the National Park of Pendjari is dominated by 4 main classes of land cover. There are

- Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m), which represents 62.32% of the whole area of the commune of Tanguieta and 79% of which burned.
- class 110, Mosaic forest or shrubland (50-70%) / grassland (20-50%) which represents 17.31% of the areas of the commune. Almost all the instance of this land cover area burns (90% of its areas)
- class 20, Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest)represents 13,40% of the area of Tanguieta. 72% of its total area is burned.
- class 60, Open broadleaved deciduous forest/woodland makes also about 7% of the total area of the commune.

Since almost the whole investigated area burned, the contributions of these land cover class to the overall burned areas are also the same as the ratio of their areas to the overall vegetation size (Figure 6.2).

More than 90% of rainfed croplands, Mosaic cropland, and shrublands burned this year. The areas that experienced few or almost no fire are evergreen or semi-deciduous forest and flooded areas (Figure 6.2, figure 6.5 and figure 6.6).

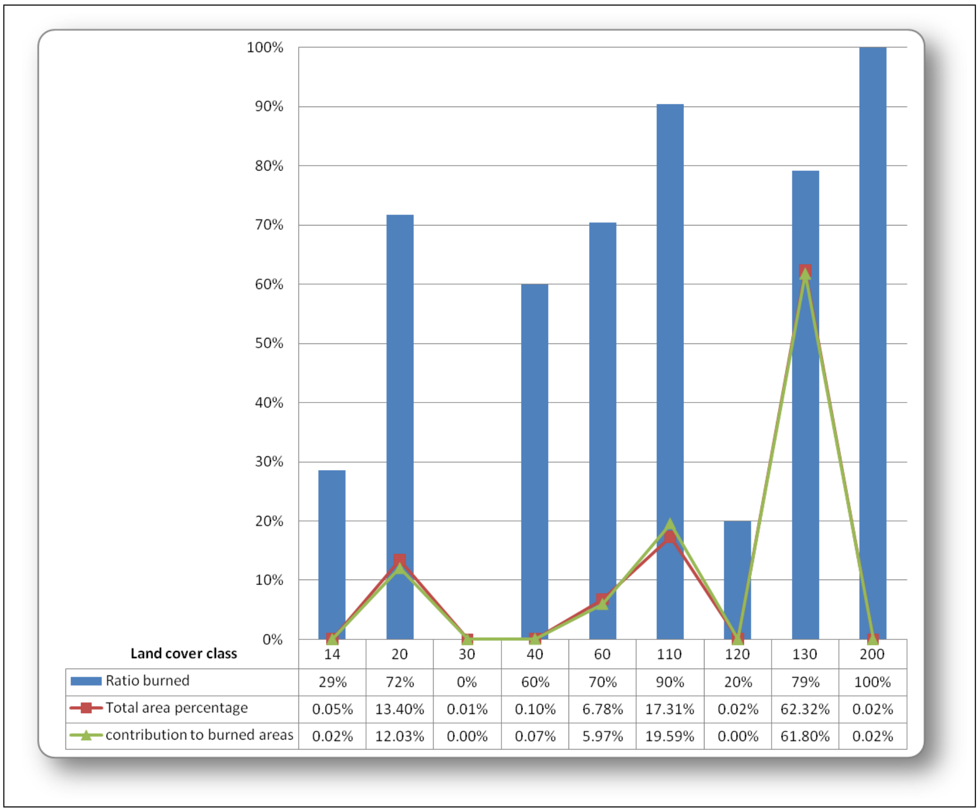


Figure 6.2: Burned area in Pendjari Park during the fire season 09/2005-08/2006: ratio of land cover types burned

6.2.3.2 Spatial and temporal distribution of fire in relation to land cover

In this subsection, the spatial and temporal distribution of fire is related to the spatial pattern of land cover. Here, only the land cover of 2004-2006 is used as mentioned above. That is the only one available now free and reliable. Considering the role of fire in shaping vegetation structure (see chapter 1) and the high fire instance in the park (see previous sections), the only 2005-2006 fire season information, which is the most closest to the period where the land cover is assessed, is used.

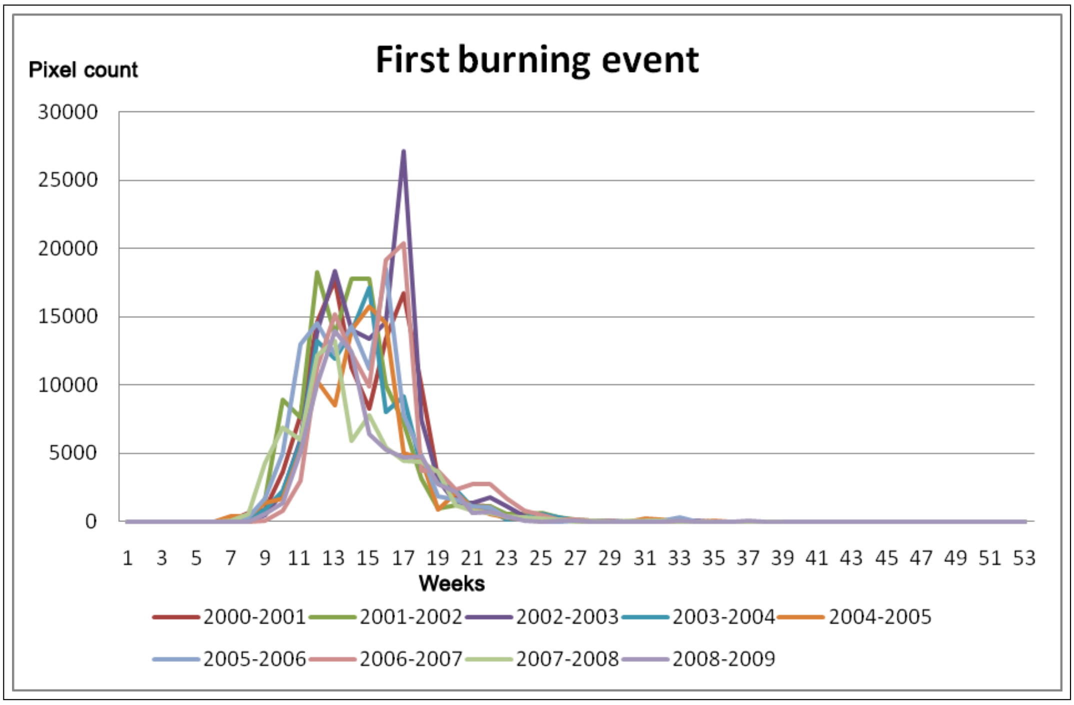


Figure 6.3: First burning event weekly distribution every year 2000-2009

The fire events occurrence in space and time shows to be related to the land cover type (Figure 6.5 and figure 6.6). The early burning event are observed in Mosaic Forest-Shrubland (class 110) in the second and third weeks of November. In December and January burn mostly Closed to open shrublands (130). Then, later in February, Mosaic Grassland-Schrublands/Cropland (class 30) are burned. This land cover type (class 30) do not burnt in the areas of the mountains Atakora. Close to Open broadleaved evergreen or semi- deciduous forest burned very lately in the first week of February (see figure 6.7).

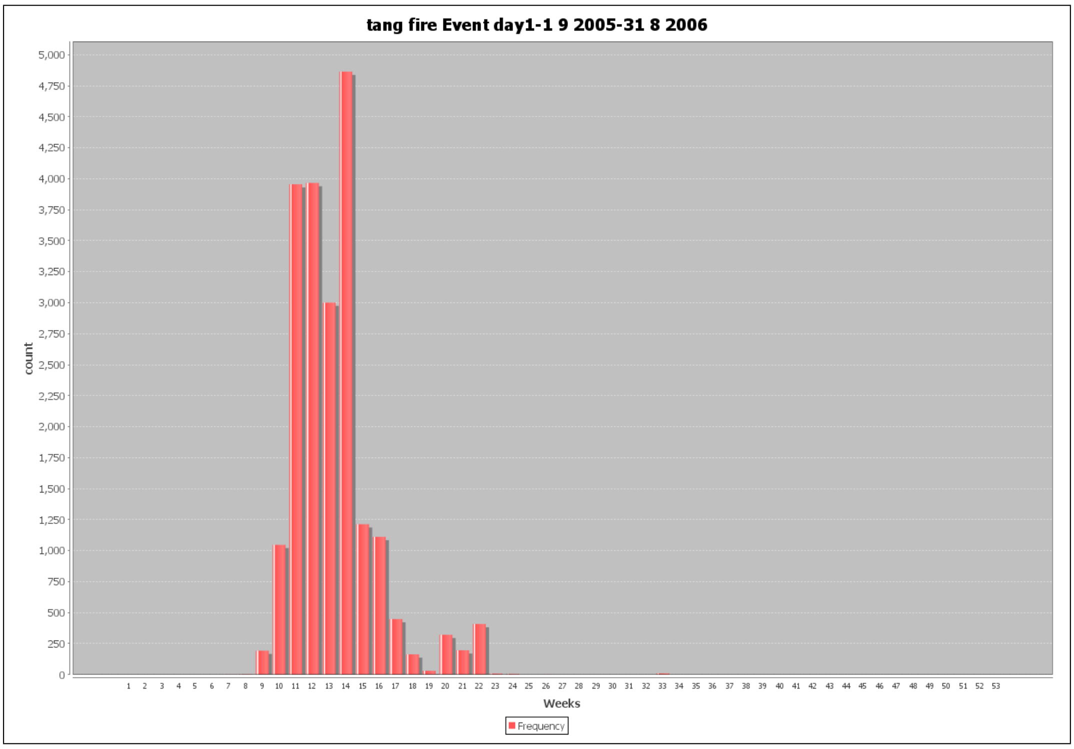


Figure 6.4: Bush fire temporal distribution in 2005-2006 at Tanguieta

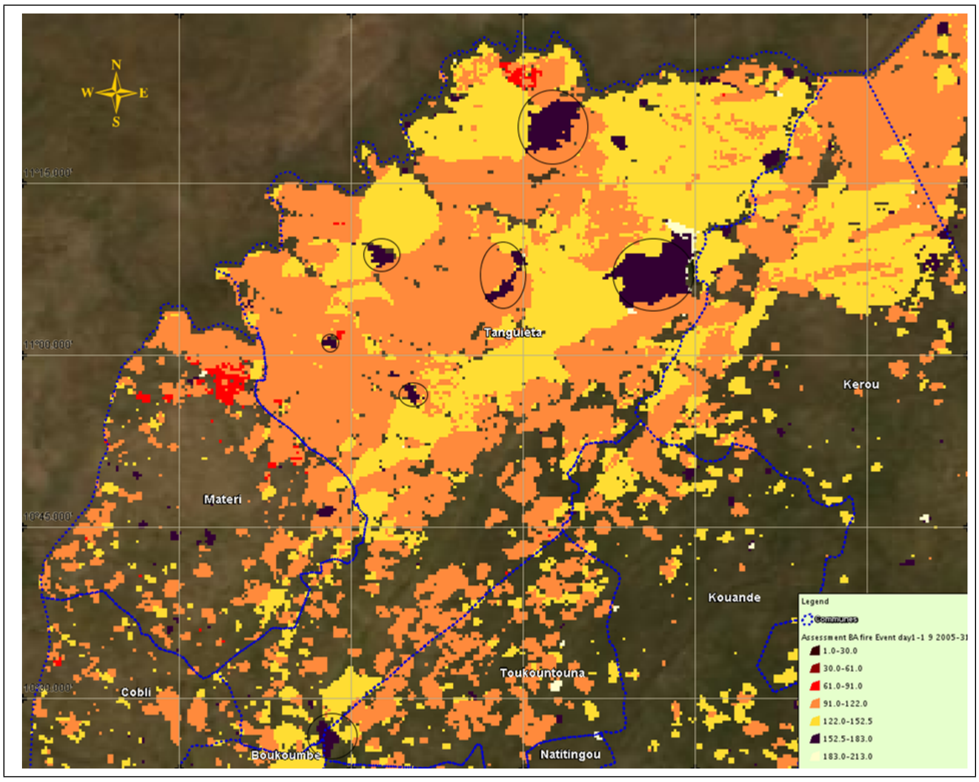


Figure 6.5: Spatial and temporal distribution of bush fire in season 2005-2006 (Tanguieta): The circle annotations show correspondence to land cover type in Figure 6.6

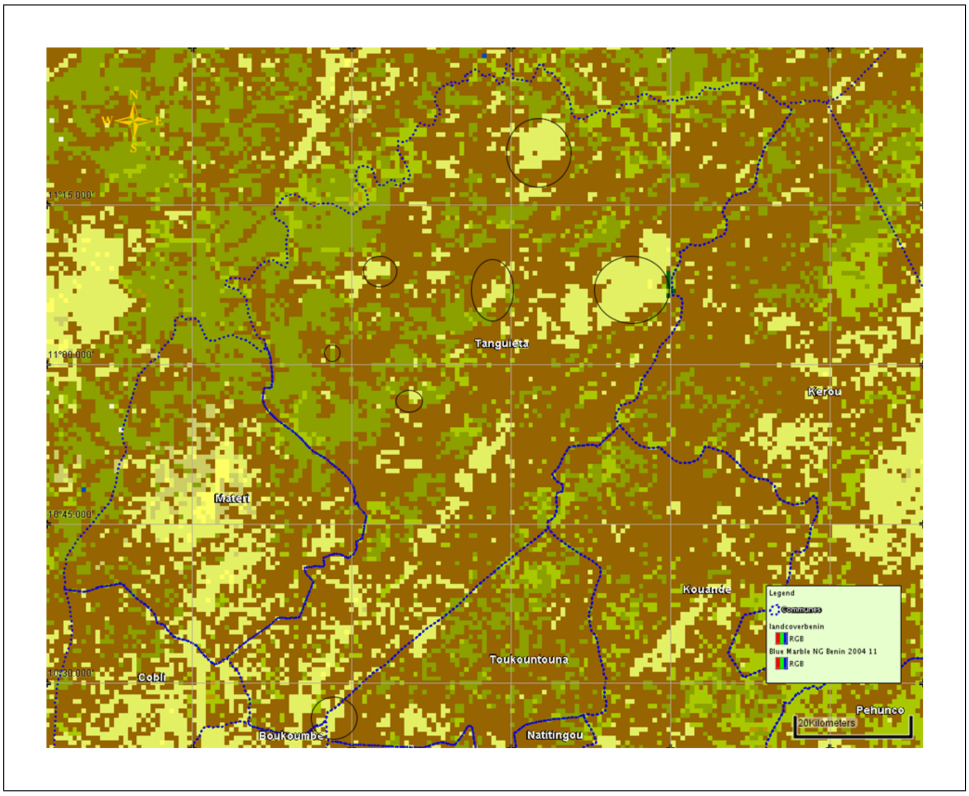
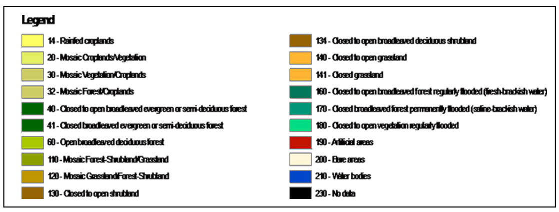


Figure 6.6: Land cover 2004-2006 (Tanguieta) (Data source: Bicheron et al. (2008))



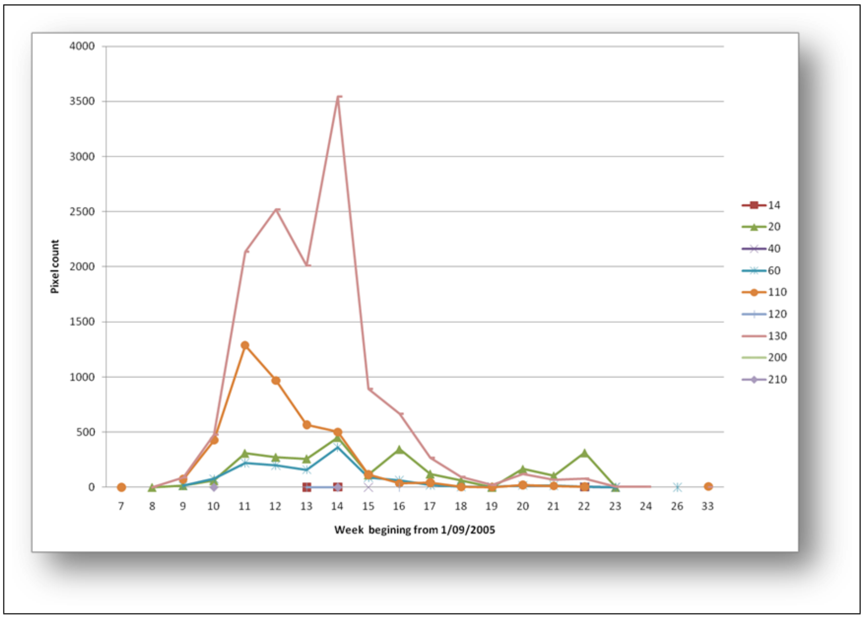


Figure 6.7: Timing of bush fire from 09/2005 to 08/2006 related to land cover types 2004-2006.

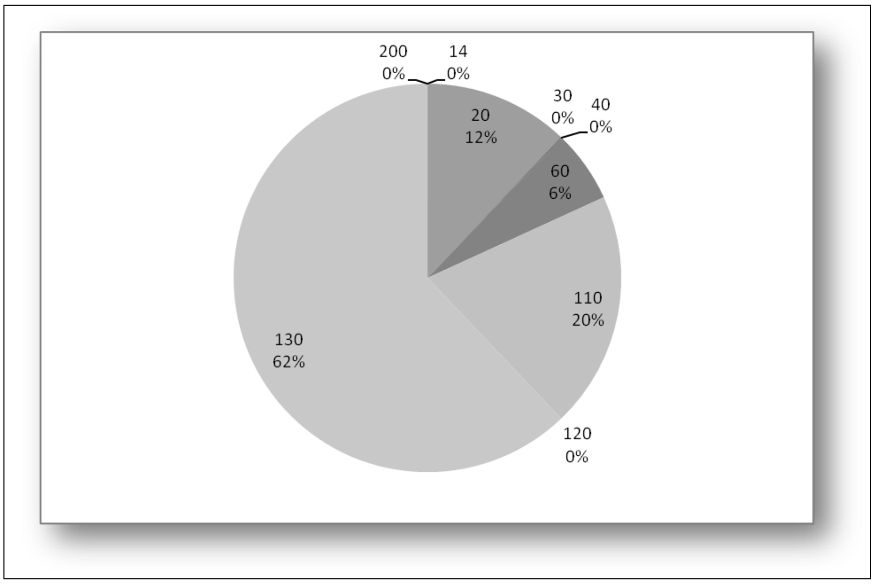


Figure 6.8: Distribution of burned area per land cover in Tanguieta commune

6.2.4 Fire distribution versus rainfall

This subsection presents the pattern of rainfall in various stations around the commune of Tanguieta. These rainfall measurement stations include Kouande, Natitingou, Tanguieta. The distribution of the number and the amount of rains shows similarities over the time period between stations. The dry season, generally starts about the first week of November and ends in February. The wetter month is August (see figure B.1 to figure B.8). From observation of the charts it could be noticed that timing of bush fire follows the one of dry season. The observation of the charts suggests no apparent relationship between the rainfall amount or rainfall event number and the total burned area for the years considered. Therefore no statistics test is realized.

6.3 Discussions

Distribution of first fire event day can be used along with distribution of rainfall to defined dates of prescribed fires. That is, based on the distribution of the first burning and the late rainfall event for a commune for the previous year, the decision-maker can decide to bring forward the previous prescribed date in order to make the fires occur earlier. The result of this statement will be assessed using the distribution of the fire events and the health of different land covers the following year. The map of the last burning event can be used to verify the compliance to the statement of the prescribed date of the previous fire season. As shown in the chart relating burned areas to land cover (Figure 6.2), the shrublands, croplands and grasslands are almost burned at 90% while the evergreen forests do not. As explained by Bond and van Wilgen (1996), savanna, shrublands, shrubs and grasses are highly flammable plants because of their relatively low moisture contents. The evergreen forests remain green throughout the year hence the likely of burning is almost zero. That reveals that almost areas burned once when the vegetation is flammable (dry). The information on the distribution of fire event date in relation to land cover can also complement the information need to state the prescribed fires dates. Using this information the dates can be specified differently for each land cover. The large proportion of burnt area in protected areas can be attributed partially to the fact that in these areas the vegetation is continuous. In addition, after Bond and van Wilgen (1996) fine plant parts are arranged so as to form a fuel-air matrix that optimizes propagation of fire. This feature favours the quick burning. Another reason could be the fact that, in most protected areas prescribed fire management system is adopted so that it burns regularly every year. It is important to note that these areas belong to the savannah areas dominated by grassland and shrublands which are known as fire prone. The areas that are outside the protected areas burned lately. These areas are mostly croplands. In southern part of the country less wildfire are observed for two main reasons. First rainfall is more important at that area and secondly, most of areas are sparse croplands with little fuel load. Croplands are more important there because of the relatively high population density. One thing important to note though is that the detection of fire in those southern areas is not very accurate, since they are mostly covered by clouds.

The extension of late burning on neighbouring areas can be attributed to the transport of burning materials by the wind to these surrounding areas. This second or more fires event do not spread wider because they are not strong enough since the fuel load is relatively not important and not continue (Press, 1987). The first early bushfires are likely to have occurred in patchy pattern.

6.4 Conclusion

The pattern of the spatial and temporal distribution of fire is described for Benin and this pattern is related to land cover and rainfall temporal distribution. The timing of fire seasons keeps approximately the same pattern since 2000 up to 2009. The season lasts from November to April. About 17% of the area of the country is burnt in the year and December is the pick month. Usually, at each location, it burns once a year but some areas can burn many times especially in protected areas. That is due to the fuel load, the early burning and the local climate condition in these areas. The burning date at each location varies from a year to another. Except gallery forest and other evergreen woodlands, all vegetation burned in the National Park of Pendjari. The type of vegetation at each area influences the spread of fire. Mosaic forest or shrubland (50-70%) / grassland (20-50%) is very flammable. Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%) (class 30) is less flammable, Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>15m) are found but in less proportion, yet 60% of their area is burned. The information obtained from the different distribution pattern can be used to make statement of the regulation of prescribed fire. The same information are valuable for the check of the compliance to this statement.

Chapter 7

Conclusions and outlook

Although fire is often seen as a disturbance for the biophysical environment, fire is usually component of the ecosystem where it occurs and the health of this ecosystem depends on it. Generally species which are living in fire prone areas are well adapted to the phenomenon. Nonetheless, some fires can cause great damages to the biophysical environment when they occur at the inadequate moment. Thus, late fires in dry season are not healthy for the ecosystem where they happen. They are indeed intense and their severity is high. There are many causes of fires but almost always people are intentional or not the main fire starters. People in Benin start vegetation fires for many reasons, including hunting, agriculture, husbandry, arson, vegetable collection, goods protection, forest management or national park management. Those vegetation fire activities are not all controlled and can result in huge damages even on local people life. Hence a sound vegetation fire assessment is very important to appraise the extent, frequency and evolution of the phenomenon. That requires systematic and objective methods. The decision makers are trying their best to fight against fire but the process is challenging and need improvements. They need objective information to base their decision on. Remote sensing and GIS are seen as reliable technologies that can assist in those assessment tasks. This is as relevant as many satellite imageries related to fire are now available free of charge. As it happens, MODIS products series are one of those quite good datasets, freely accessible and very appropriate for such studies. But for almost a decade these products have been delivered in formats that are not always end-user friendly. The user generally has to use other tools to do manually the conversion of the data in a more convenient format then process them afterwards. That process is not always appropriate for batch processing. Moreover, it appears more interesting to couple those datasets to other sources of information and to derive comprehensive analytical and synthetic results. The development of FIMAT prevents the user from the above mentioned annoying tasks and enables the integration of additional data. It offers automatically downloading, mapping, statistics calculations, charting, animations creation, all those results that the decision maker need for his decision making process in fire assessment task. FIMAT delivers information needed for early fire prescription. It allows the decision makers to check if regulations on vegetation burning are respected. In comparison to existing fire management decision support, FIMAT allows more customization of outputs. For instance map symbolization is more flexible. The analysis performed in FIMAT can be still run off-line. The user can thus beforehand prepare the data then use later FIMAT to process them when he does not any more have access to Internet. That is very important in developing countries where access to Internet is not easy. Another advantage of FIMAT is that it allow the user to use own ancillary data in analysis and mapping process. This feature is not yet available in tools such as FIRMS. From the use case of FIMAT for Benin, many conclusions are drawn about vegetation fire pattern in the area. As a matter of fact fires keep an almost constant pattern for more than a decade in Benin. Fires happen in dry season from November until April/Mai. They occur mostly once in the fire season, but in some areas they can be observed twice, three times and rarely four times. Those multiple occurrences are generally at the fringe of late burned areas, mostly in protect areas and are extensions of late bushfires on the early burned areas. Burned areas in protected areas are wider and that may be the result of fuel load in those protected areas. Outside the protected areas, fires are later and often related to agriculture activities of local populations. Fires are related to land cover types and grasslands and shrublands are the most fire prone land cover types in Benin. This work offers new insights into the possibilities in implementing an objective fire assessment and monitoring activities using free on-line resources. The spatial resolution is still coarse for more details studies. For example it would be more interesting if data of higher resolution can be used for the detection of fire in plantations. Those vegetation types are often small but are very important. Moreover, availability of grids of meteorological data can allow more modeling features. If such data were available, they could be used in FIMAT to estimate fire risk. A regular grid of temperature for instance can be used to study fire intensity in relation to land cover type. It is a step toward a more extensible tool for disaster monitoring at different scale using global satellite data series at various spatial and temporal resolutions.

Appendix A

Acronyms and Abbreviations

AFGRN	Association des Femmes pour la Gestion des Ressources Naturelles
AS	Alibori Supérieur
CDCPRN	Chef Division Contrôle et Promotion des Ressources Naturelles
CeCPA	Centre Communal pour la Promotion Agricole
CeCPA	Centre Communal pour la Promotion Agricole
CeRPA	Centre Régional pour la Promotion Agricole
CIGRN	Comité Intervillageois de Gestion des Ressources Naturelles
CRFR	Conseil Régional des Femmes Rurales
CRJA	Conseil Régional des Jeunes Agriculteurs
CRP	Conseil Régional des Planteurs
CRPR	Conseil Régional des Producteurs de Riz
CRPV	Conseil Régional des Producteurs de Vivriers
DAAC	Distributed Active Archive Center
DAFM	Division des Affaires Financières et du Matériel
DAGRN	Direction de lAménagement et de la Gestion des Ressources Naturelles
DCPRN	Division Contrôle et Promotion des Ressources Naturelles
DDEPN	Direction Départementale de lEnvironnement et de la Protection de la Nature
DES	Division des Etudes et de la Synthèse
DFPRN	Direction des Forêts et de la Protection des Ressources Naturelles
DG/CeRPA	Direction Générale du Centre Régional pour la Promotion Agricole
DGFRN	Direction Générale des Forêts et des Ressources Naturelles
DIFAOP	Direction de lInformation, de la Formation et de lAppui aux Organisations Professionnelles
DK	Dogo Kétou
DP	Division du Personnel
DPAF	Direction de la Programmation, de lAdministration et des Finances
DPE	Division de la Police Environnementale

Continued ...

DPSA	Direction de la Promotion des Filières et de la Sécurité Alimentaire
DPSSE	Division de la Planification, de la Statistique, du Suivi et de lEvaluation
DRC	Direction de la Réglementation et du Contrôle
DRCC	Division de la Réglementation, du Contrôle et du Contentieux
DRE	Division de la Réglementation Environnementale
DSIF	Division des Services de lIntendance Forestière
DVF	Division de la Vulgarisation et de la Formation
EDOS	EOS Data and Operations System
EGS	EOS Ground System
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
EPA	Equipe Pluridisciplinaire dArrondissement
ESA	Equipe de Spécialistes Agricoles
ESDIS	Earth Science Data and Information System
FAO	Organisation des Nations Unies pour lAlimentation et lAgriculture
FTP	File Transfer Protocol
GMT	Greenwich Mean Time
GSFC	Goddard Space Flight Center
HDF-EOS	Hierarchical Data Format - Earth Observing System
IF	Inspection Forestière
INSAE	Institut National de la Statistique et de lAnalyse Economique
MCST	MODIS Characterization Support Team
MECCAG- PDPE	Ministère dEtat, Chargé de la Coordination de lAction Gouvernementale du Plan du Développement et de la Promotion de lEmploi
MEPN	Ministère de lEnvironnement et de la Protection de la Nature
MODIS	Moderate Resolution Imaging Spectroradiometer
MODLAND	MODIS Land Discipline Group
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NCSA	National Center for Supercomputing Applications
NDSI	Normalized Difference fire Index
NSIDC	National fire and Ice Data Center

Continued ...

ONG	Organisation Non Gouvernementale
OPA	Organisation socio-professionnelle agricole
OSN	Ouémé Supérieur NDali
PAVICO	Projet bénino-allemand pour lAuto-Promotion Villageoise dans les Communes de lAtacora
PBF II	Projet Bois de Feu phase II
PEF	Poste Environnemental et Forestier
PEF	Poste des Eaux et Forêts
PGFTR	Programme de Gestion des Forêts et des Terroirs Riverains
PGRN	Projet de Gestion des Ressources Naturelles
PGTRN	Projet de Gestion des Terroirs et Ressources Naturelles
PNUD	Programme des Nations Unies pour le Développement
PRCIG	Programme de Renforcement des Capacités Institutionnelles et de Gestion
QA	Quality Assessment
R/CPA	Responsable du Centre Communal pour la Promotion Agricole
R/SCEPN	Responsable de Section Communale de lEnvironnement et de la Protection de la Nature
SA	Secrétariat Administratif
SAACOP	Service de lAppui à lAction Coopérative et aux Organisations Professionnelles
SAER	Service de lAménagement et de lEquipement Rural
SAF	Service Administratif et Financier
SAF	Service Administratif et Financier
SASAN	Service dAppui à la Sécurité Alimentaire et Nutritionnelle
SCEPN	Section Communale de lEnvironnement et de la Protection de la Nature
SCNQPV	Service du Contrôle des Normes et de la Qualité des Produits dorigine Végétale
SCPAH	Service du Contrôle des Produits dorigine Animale et Halieutique
SD	Solar Diffuser
SDP	Science Data Processing
SDS	Scientific Data Set
SDSM	Solar Diffuser Stability Monitor
SFGRN	Service des Forêts et de la Gestion des Ressources Naturelles

Continued ...

SFOC	Service de la Formation Opérationnelle et du Conseil aux exploitations agricoles
SGG	Sota Goungoun - Goroubi
SICAR	Service de lInformation et de la Communication Agricole et Rurale
SIN	Sinusoidal Grid
SP	Secrétariat Particulier
SPAT	Service de la Planification et de lAménagement du Territoire
SPC	Service de la Programmation et de la Coordination
SPCI	Service de la Surveillance Phytosanitaire et du Contrôle des Intrants Agricoles
SPFA	Service de la Promotion des Filières Agricoles
SRCA	Spectroradiometric Calibration Assembly
SRCCE	Service de la Réglementation, du Contrôle et du Contentieux Environnementaux
SSESD	Service du Suivi, de lEvaluation, de la Statistique et de la Documentation
SVSSE	Service de la Vulgarisation, de la Statistique et du Suivi Evaluation
TTK	Tchaourou Toui - Kilibo
UCGRN	Union Communale de Gestion des Ressources Naturelles
URP	Union Régionale des Producteurs de lOuémé et du Plateau

Appendix B
Figures

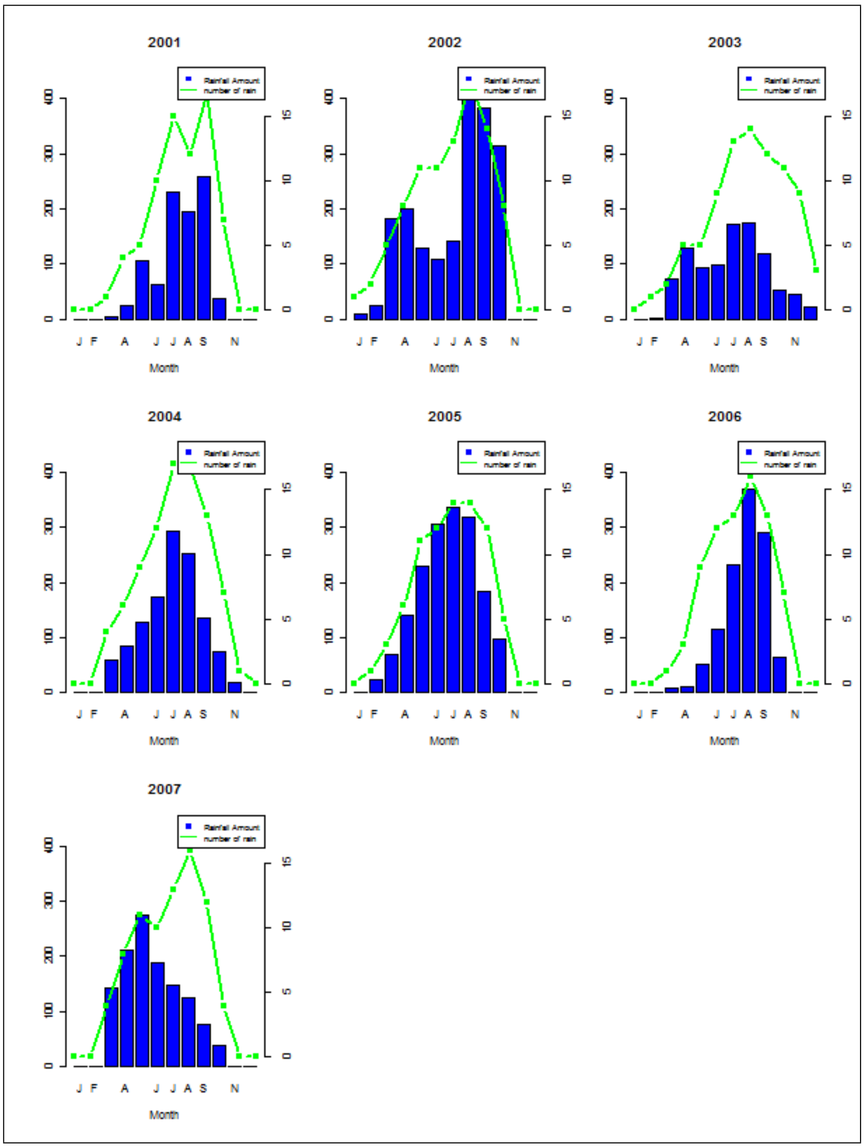


Figure B.1: Rainfall monthly distribution at station of Tanguieta

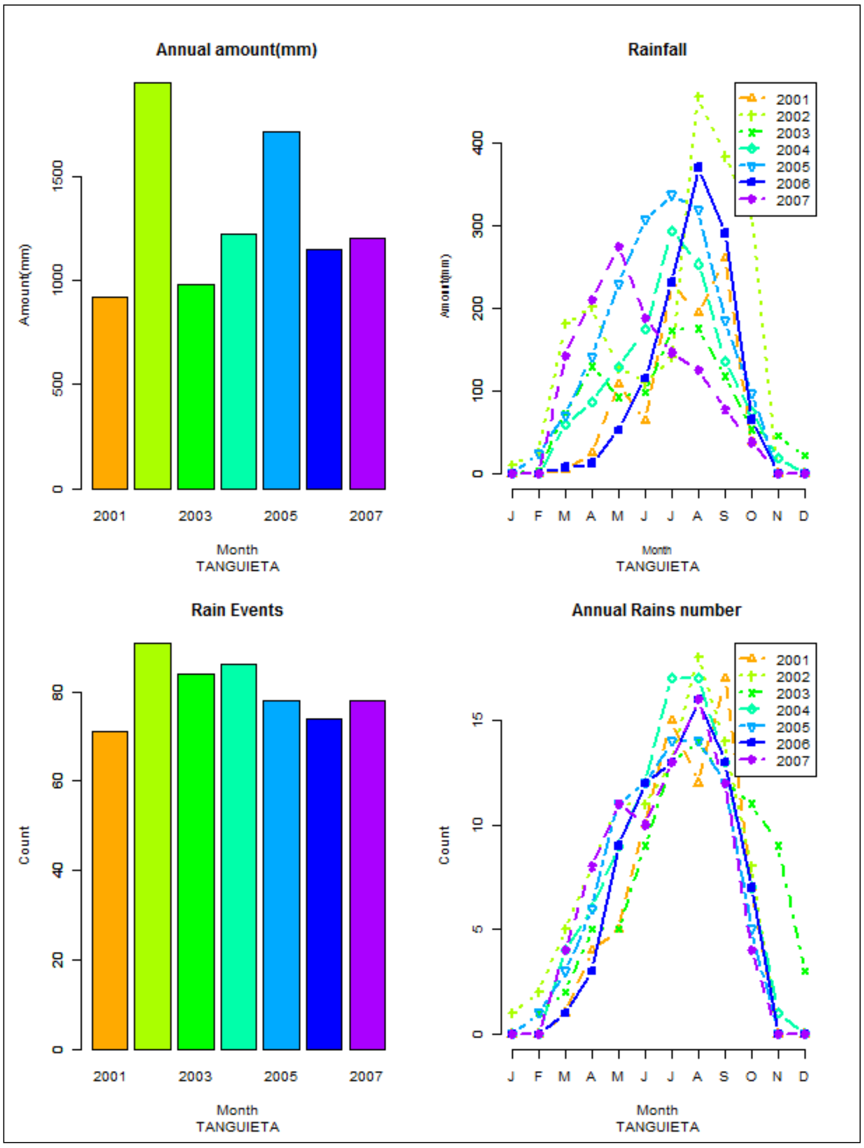


Figure B.2: Rainfall annual distribution at station of Tanguieta

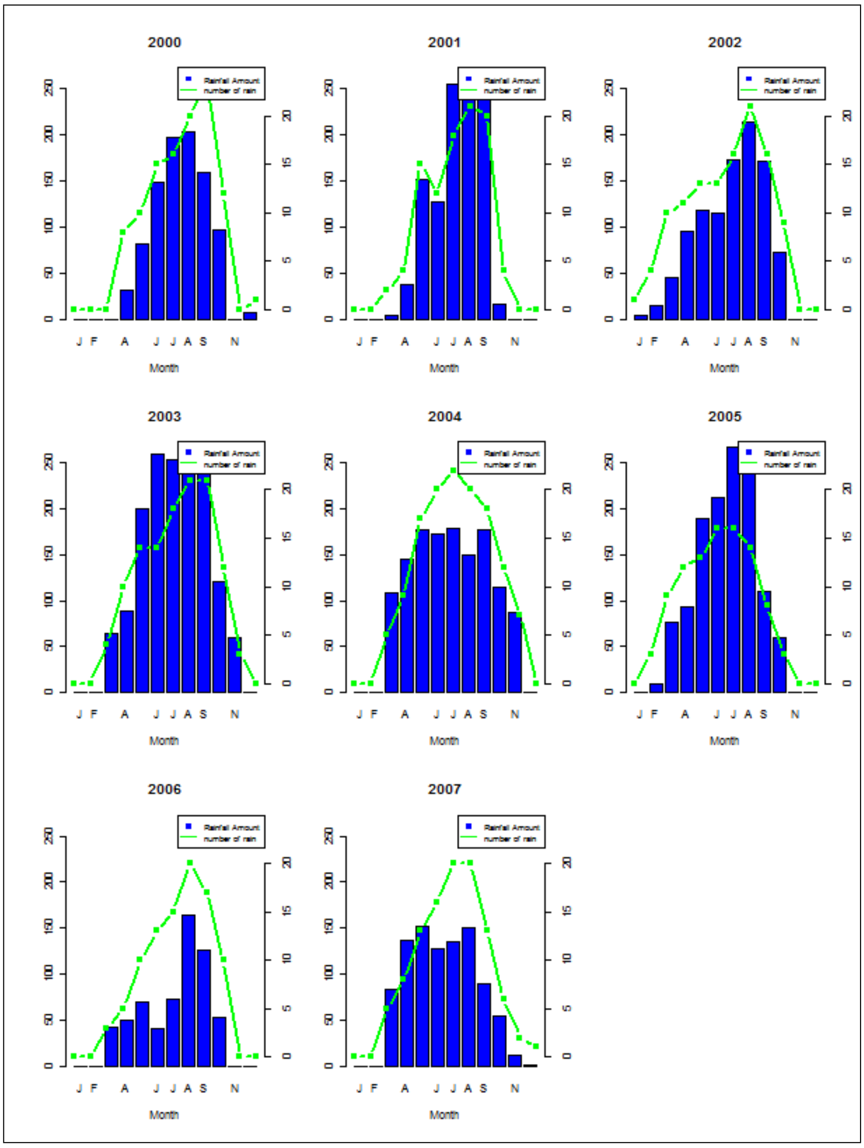


Figure B.3: Rainfall monthly distribution at station of Natitingou

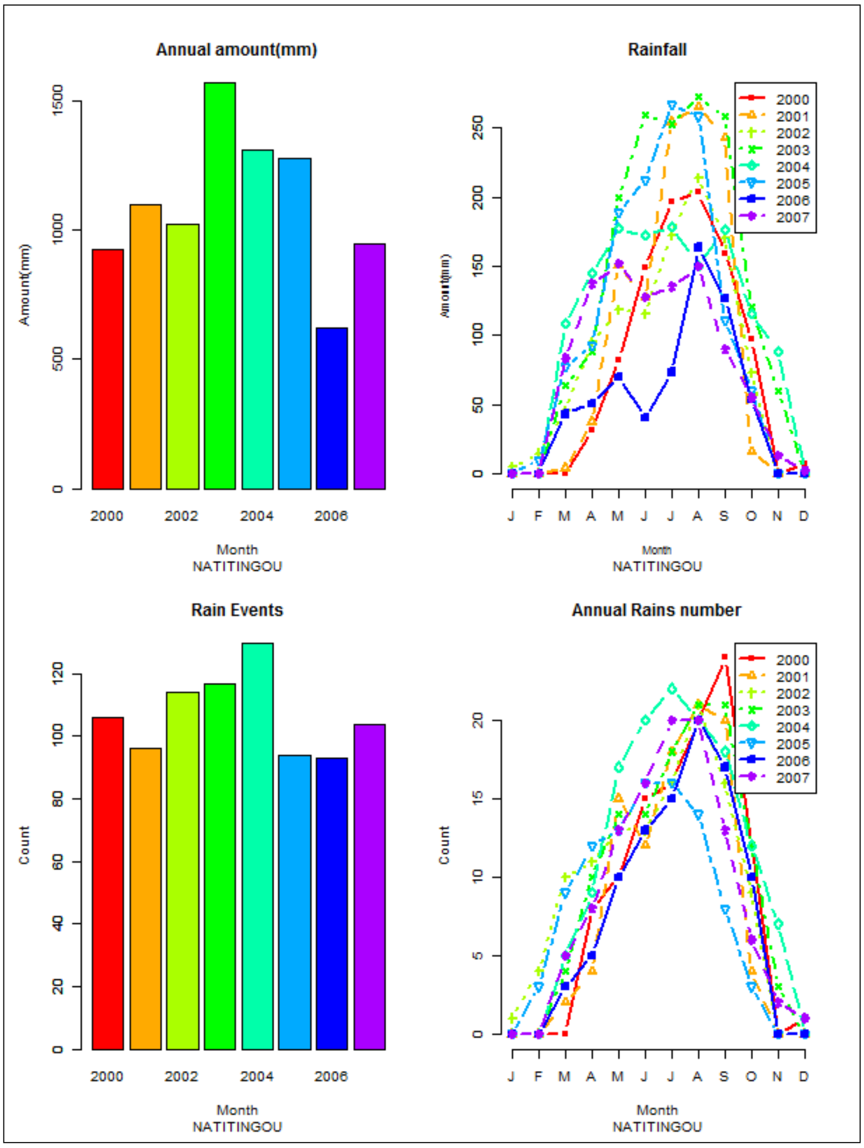


Figure B.4: Rainfall annual distribution at station of Natitingou

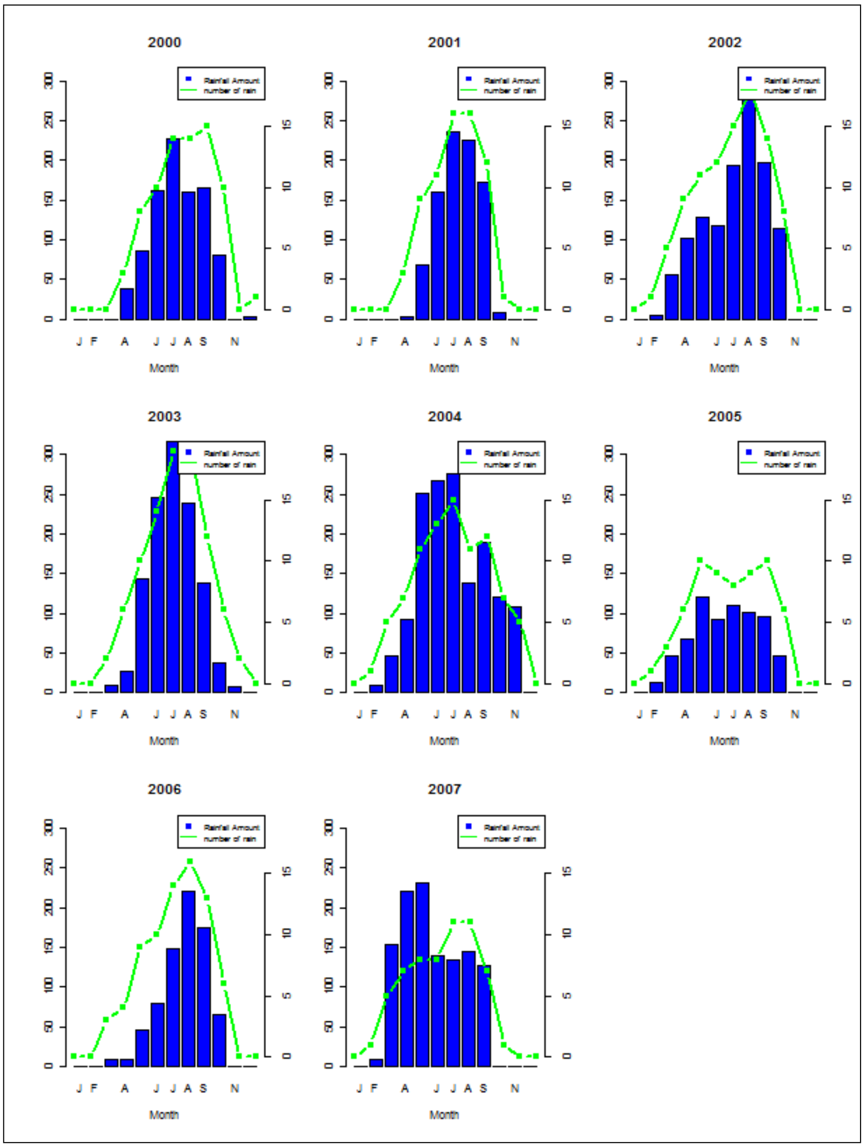


Figure B.5: Rainfall monthly distribution at station of Kouande

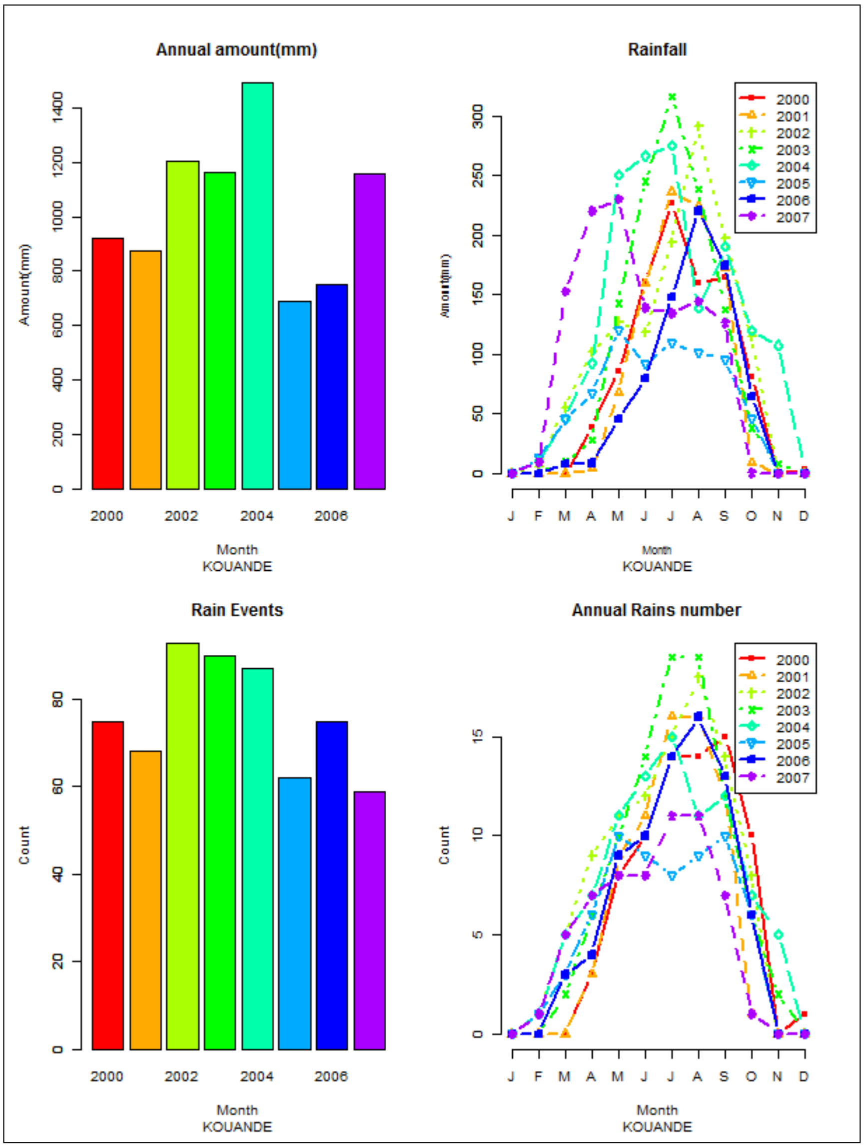


Figure B.6: Rainfall annual distribution at station of Kouande

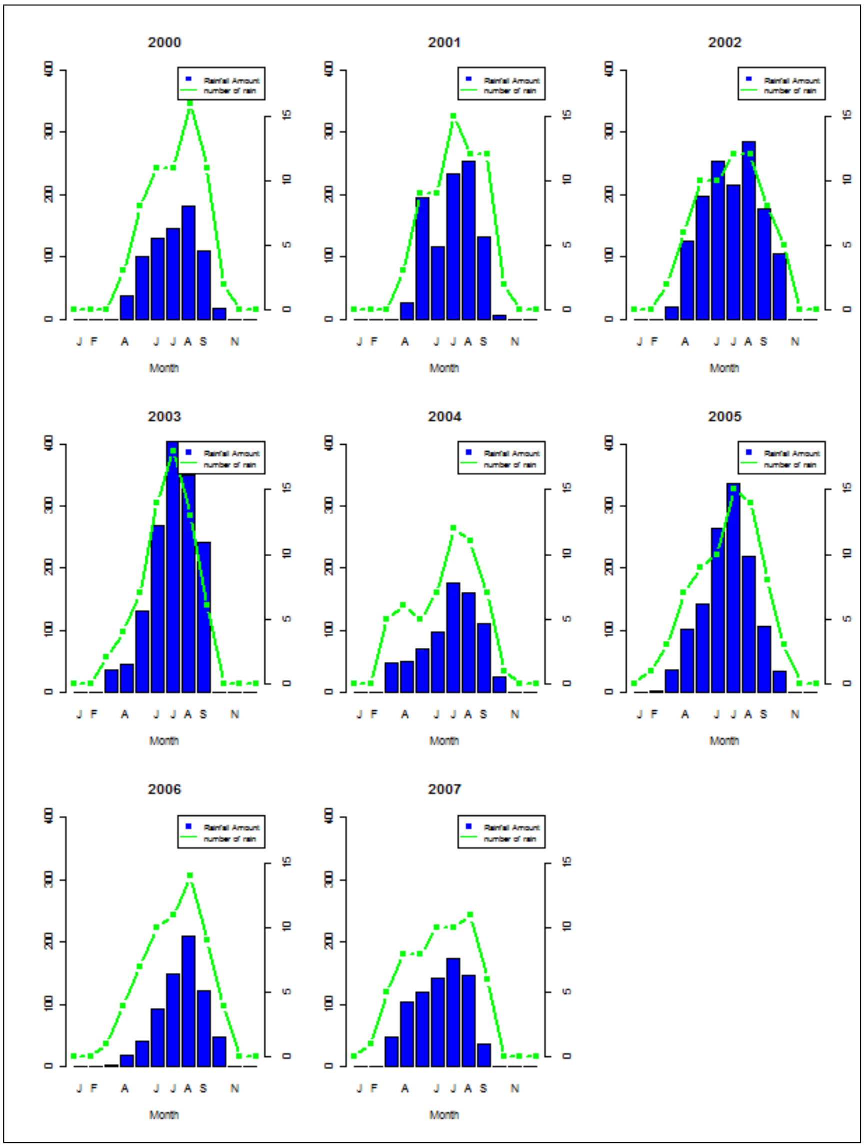


Figure B.7: Rainfall Monthly distribution at station of Banikoara

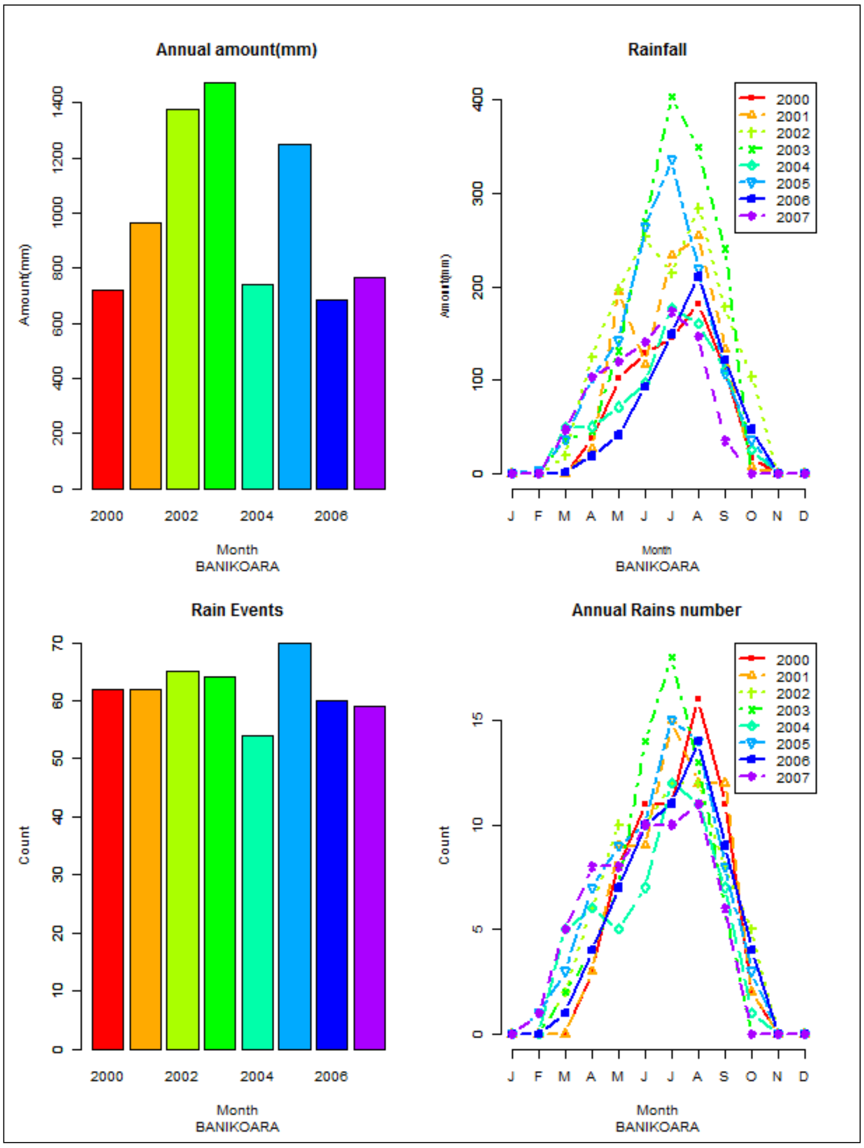


Figure B.8: Rainfall Annual distribution at station of Banikoara

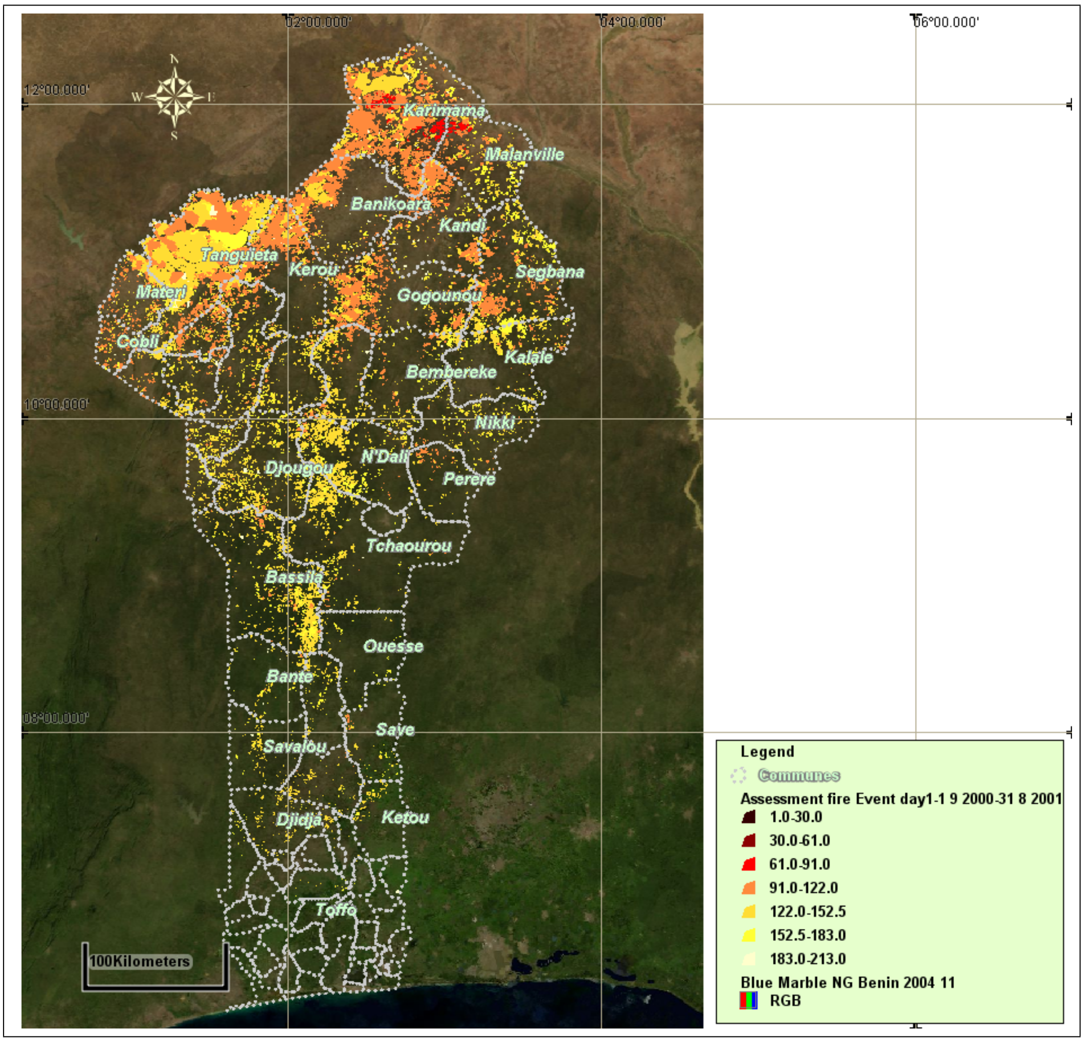


Figure B.9: Spatial distribution of first burning events as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2000- 2001. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

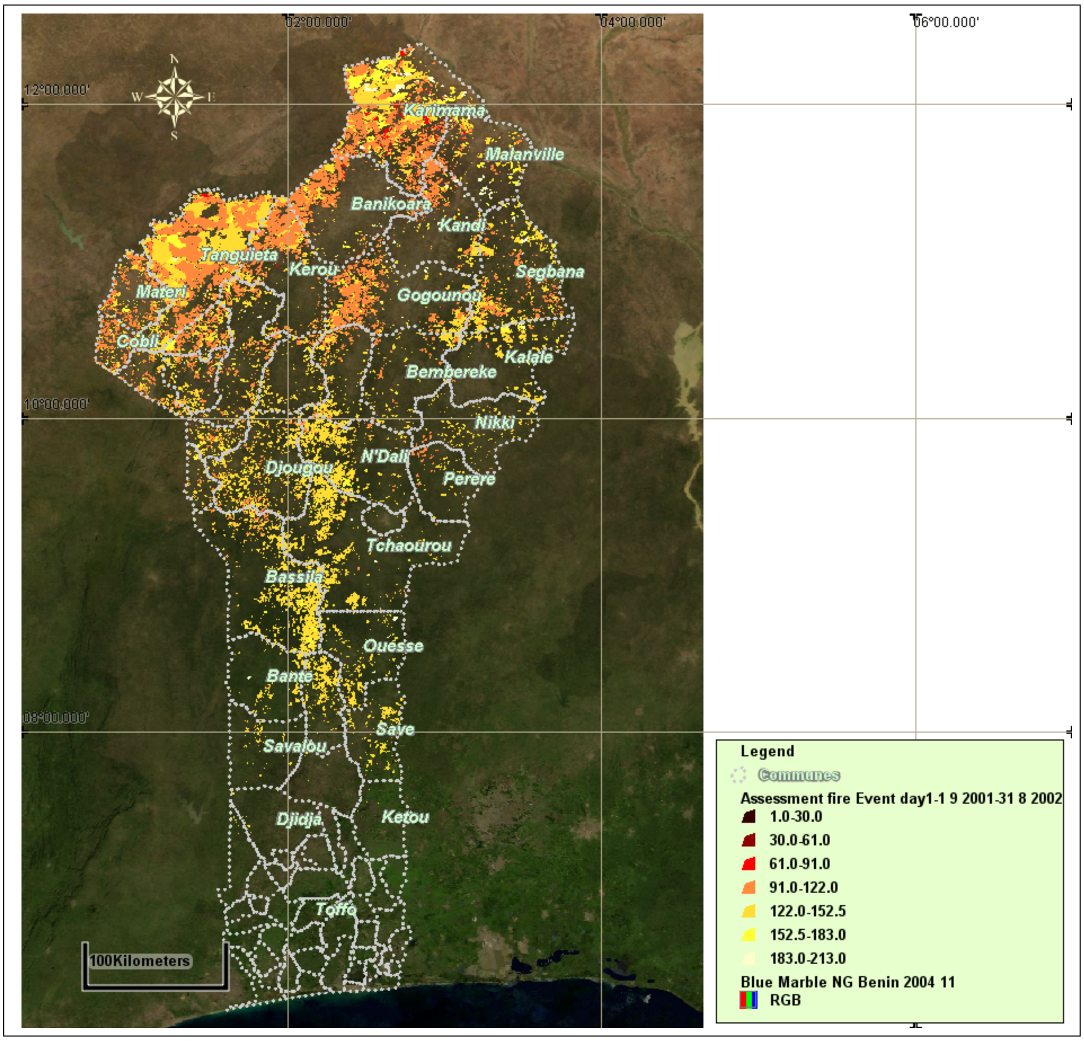


Figure B.10: Spatial distribution of first burning events as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2001- 2002. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

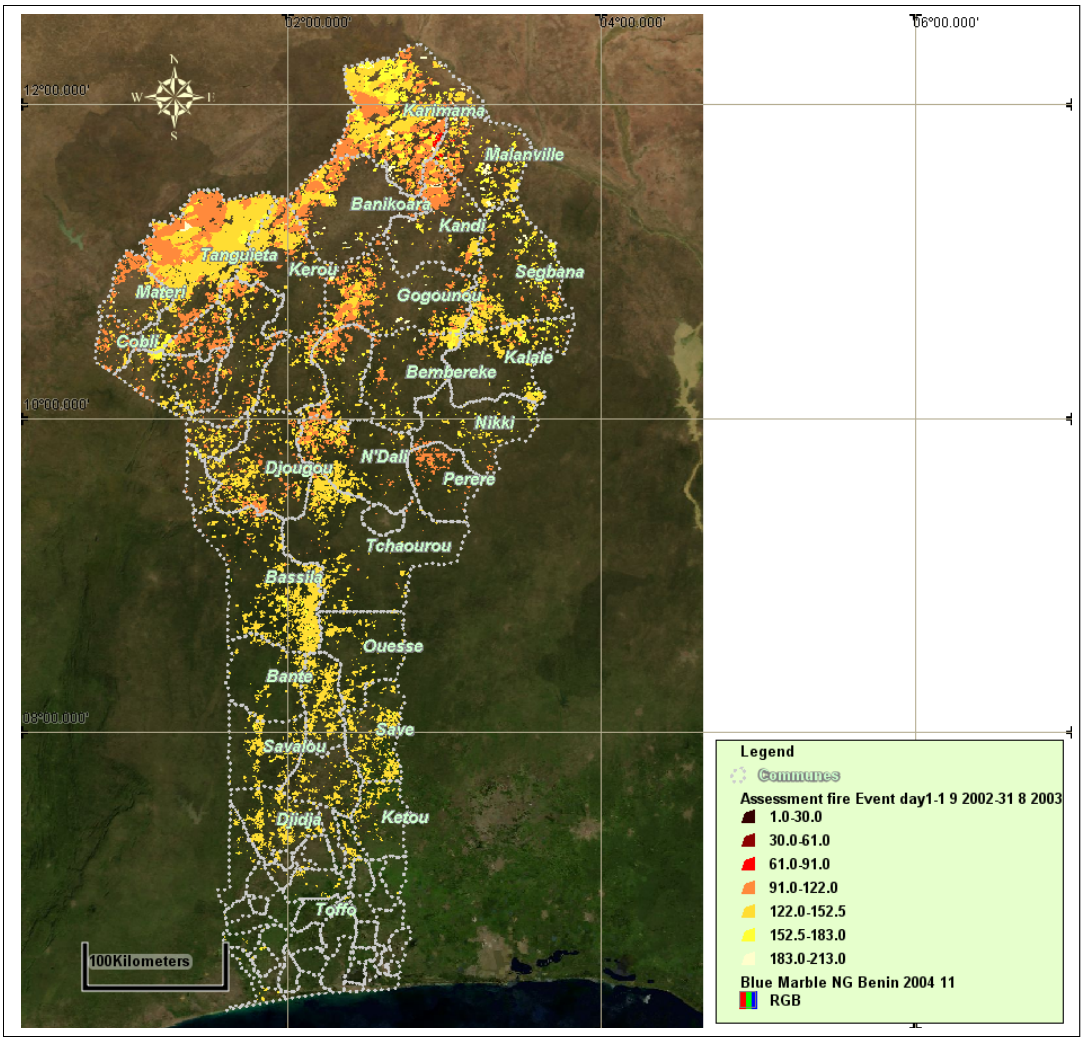


Figure B.11: Spatial distribution of first burning events as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2002- 2003. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

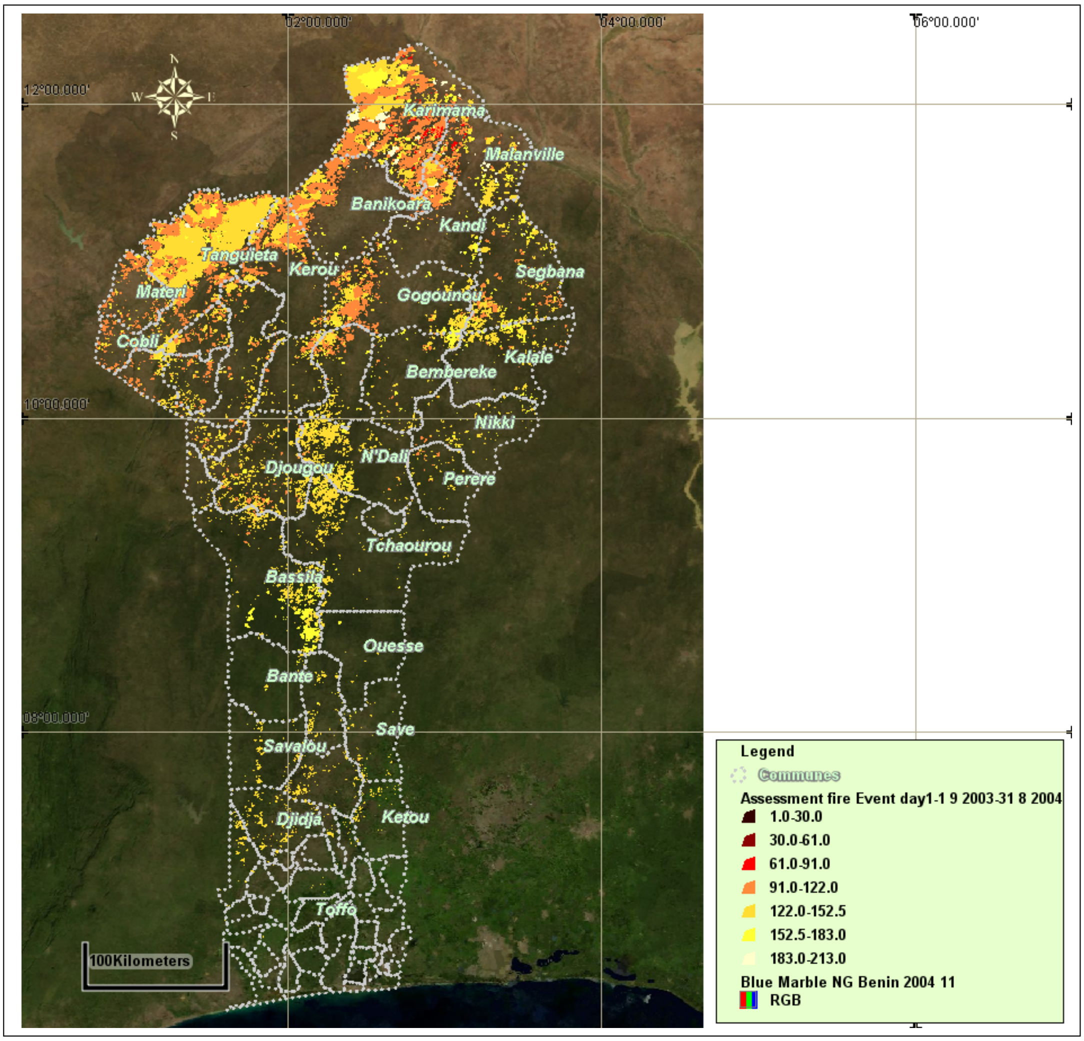


Figure B.12: Spatial distribution of first burning events as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2003- 2004. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

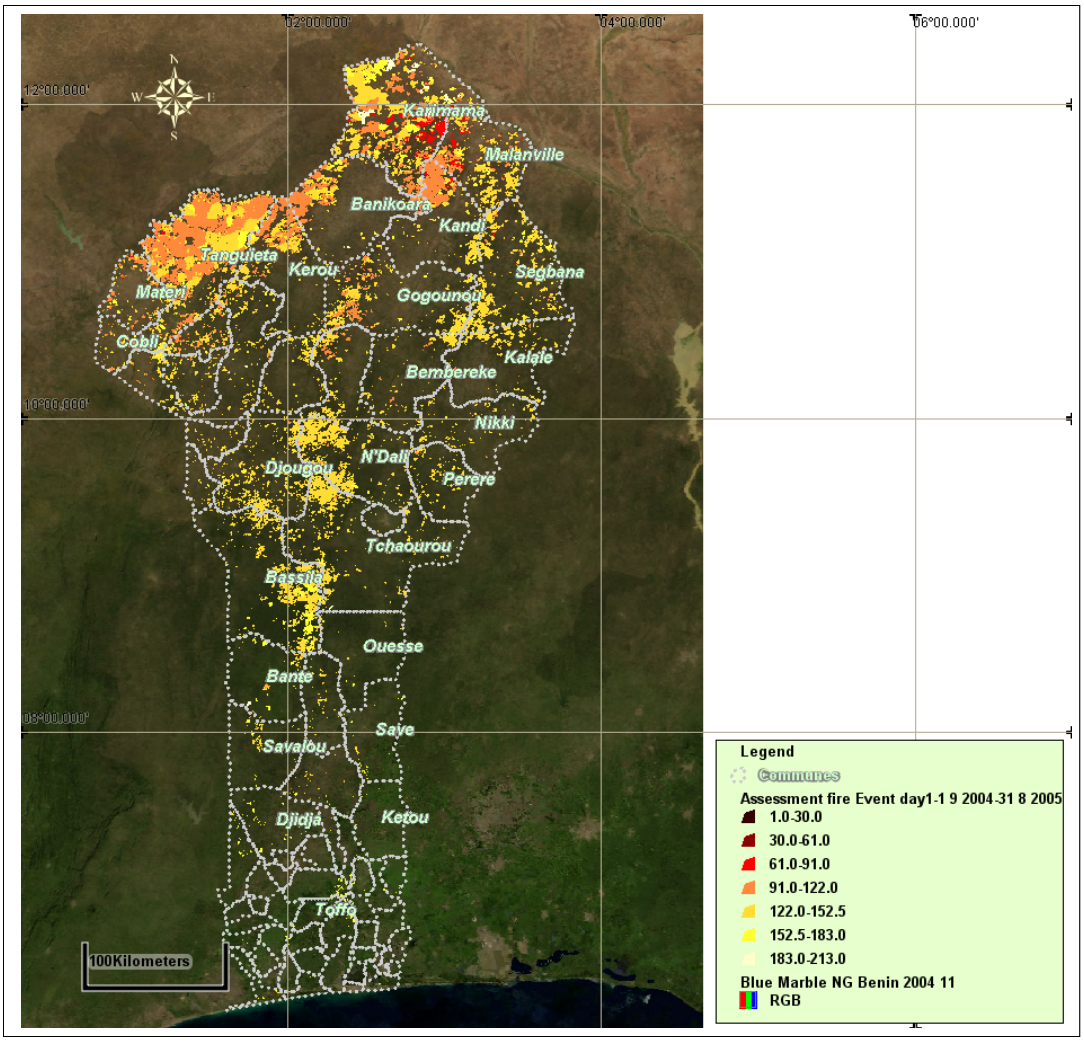


Figure B.13: Spatial distribution of first burning events as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2004- 2005. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

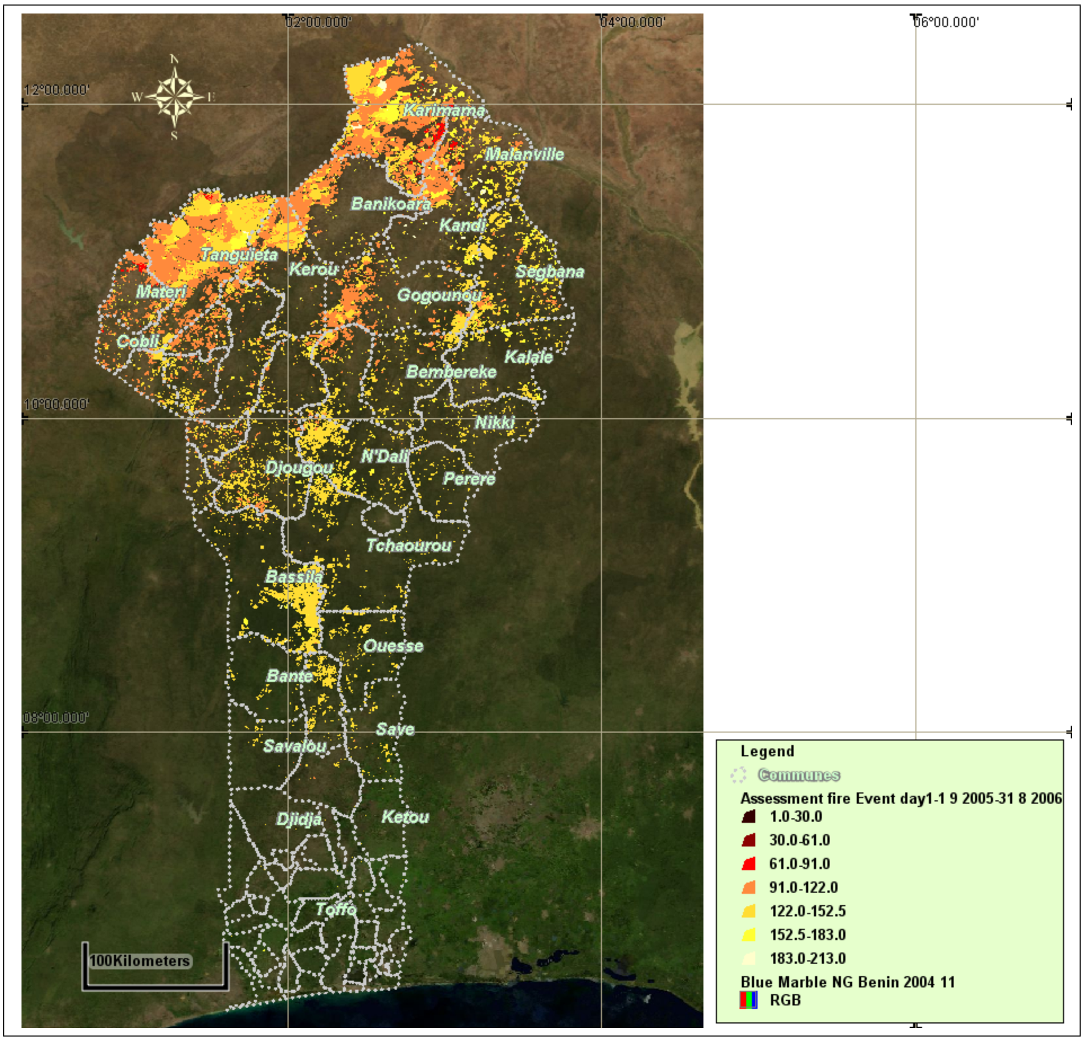


Figure B.14: Spatial distribution of first burning events as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2005- 2006. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

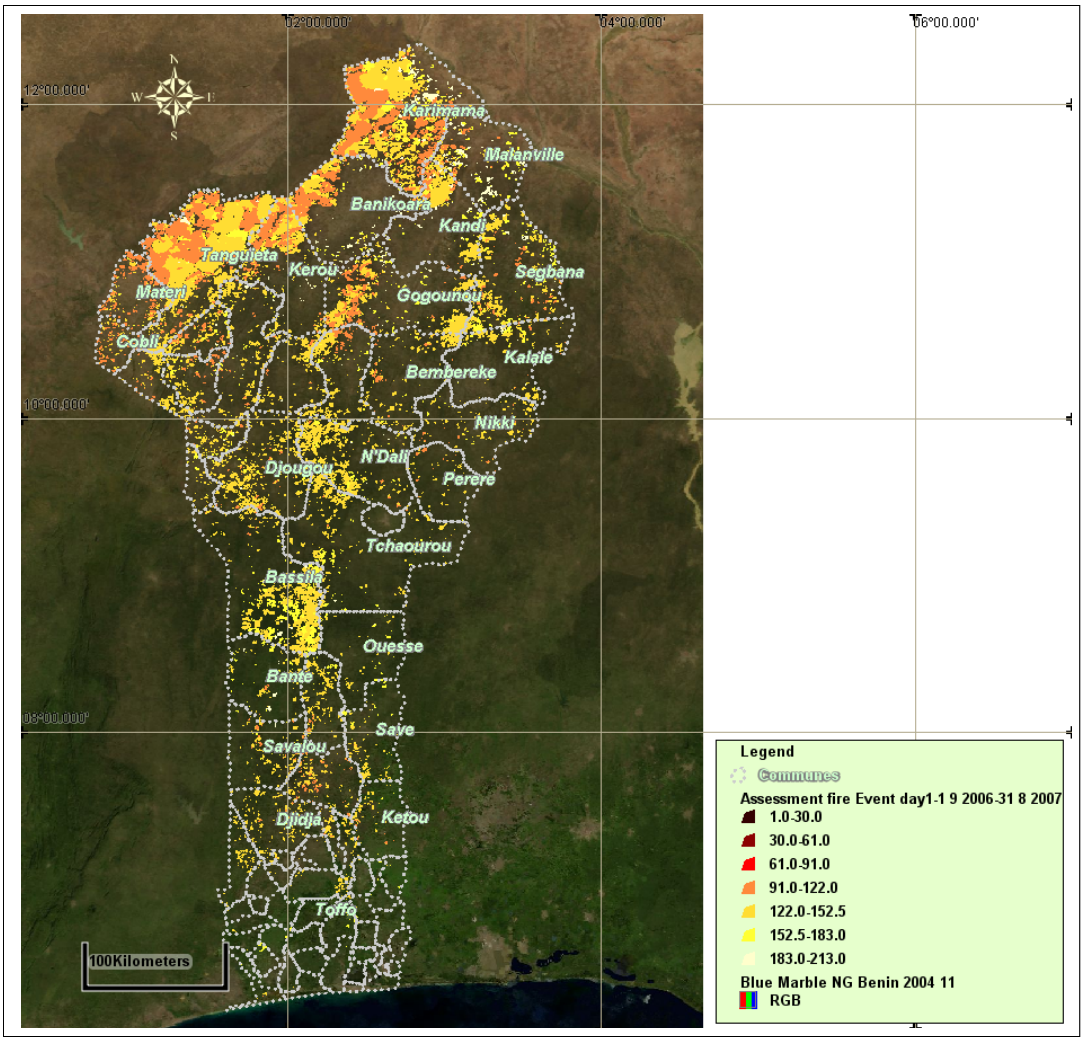


Figure B.15: Spatial distribution of first burning events as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2006- 2007. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

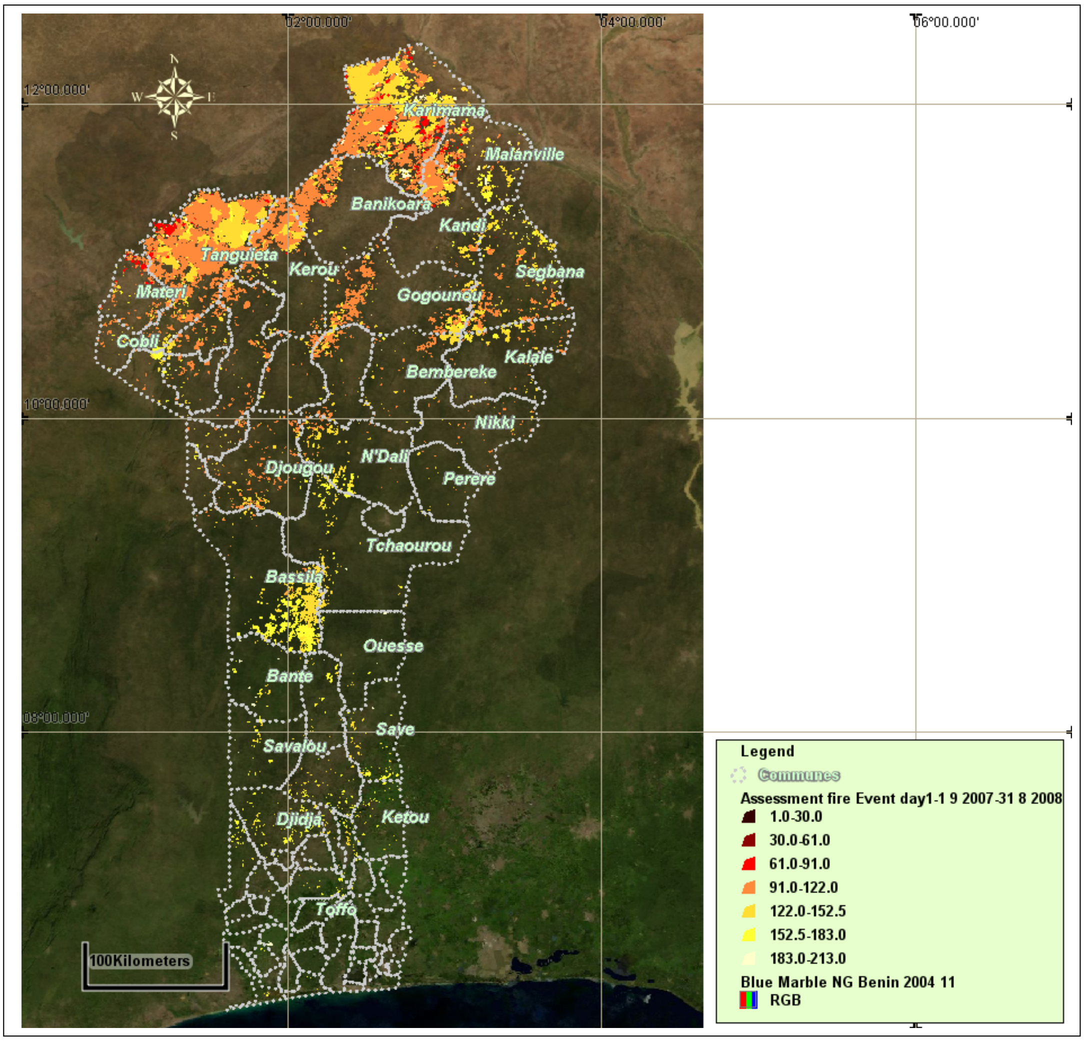


Figure B.16: Spatial distribution of first burning events as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2007-2008. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

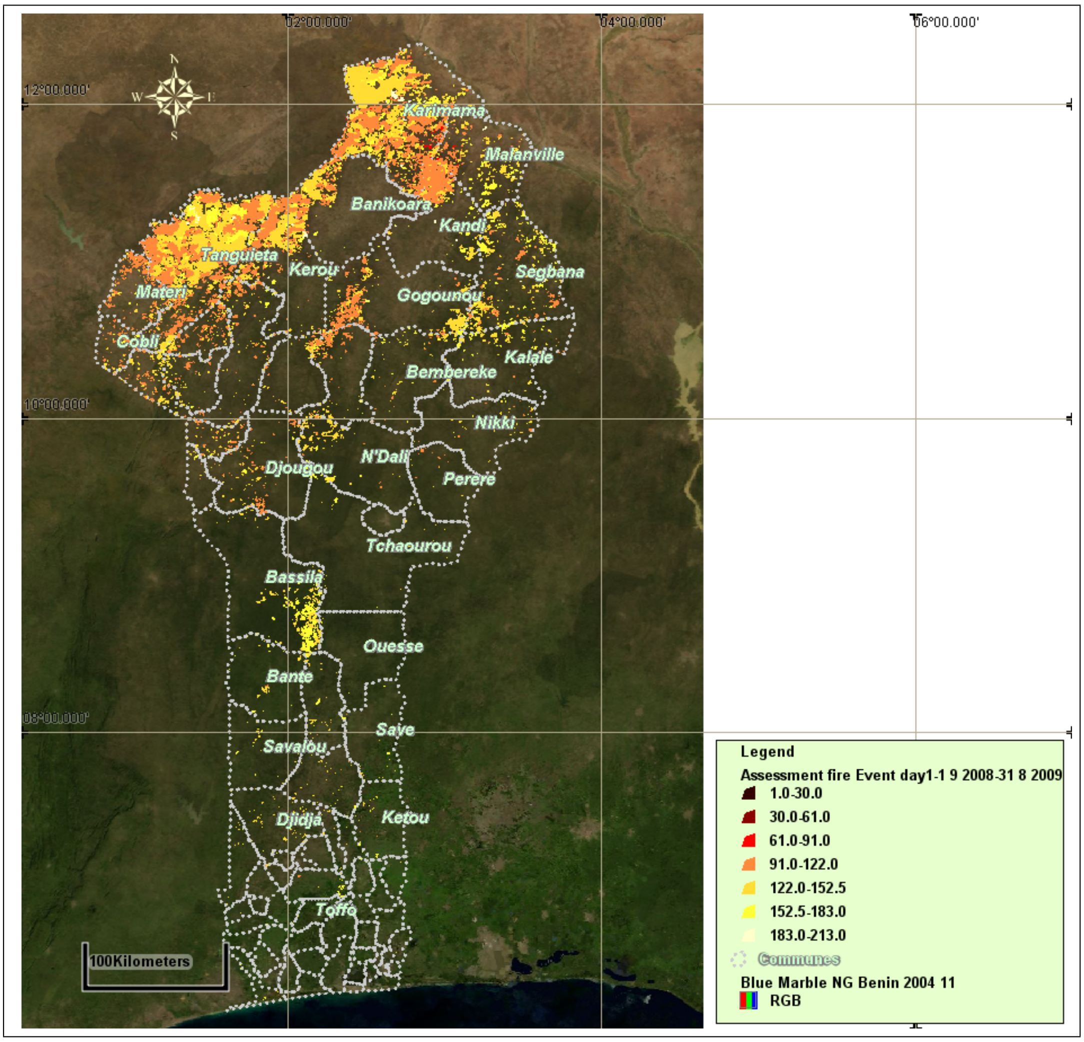


Figure B.17: Spatial distribution of first burning events as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2008- 2009. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

B.0.1 Temporal frequency distribution of early burned area

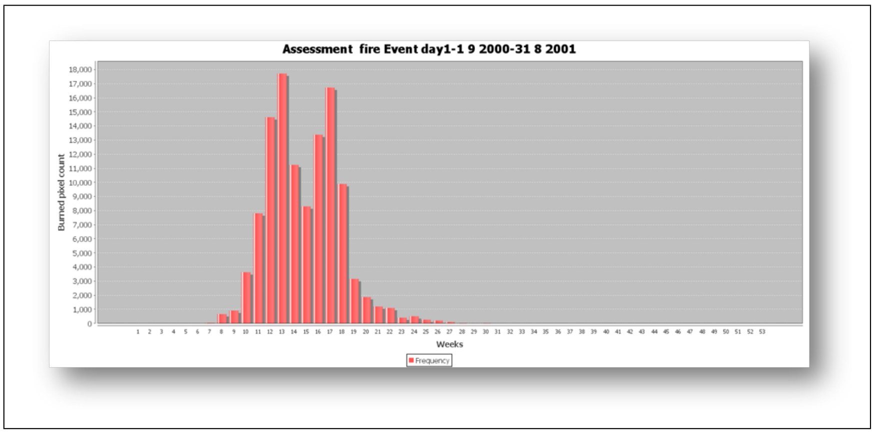


Figure B.18: First burning event weekly distribution in Benin during the fire season 2000- 2001

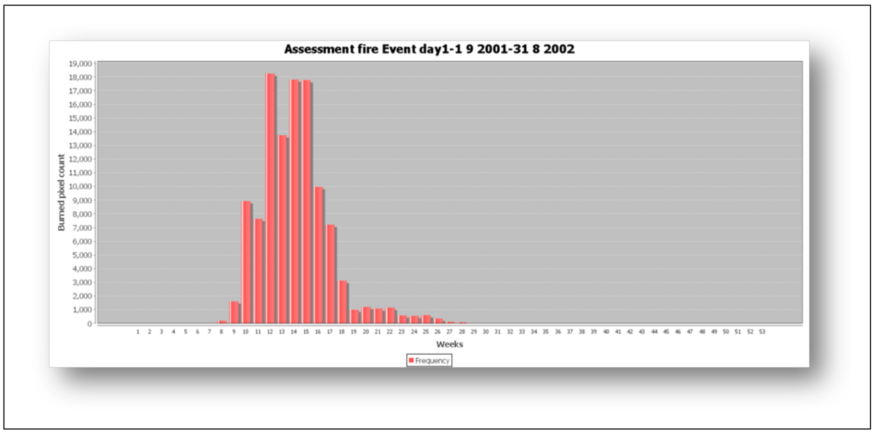


Figure B.19: First burning event weekly distribution in Benin during the fire season 2001- 2002

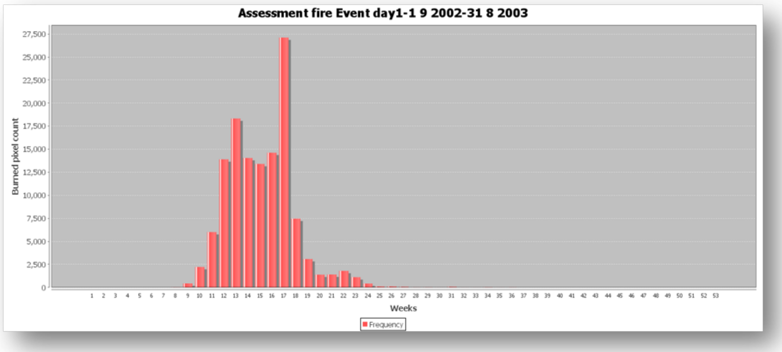


Figure B.20: First burning event weekly distribution in Benin during the fire season 2002- 2003

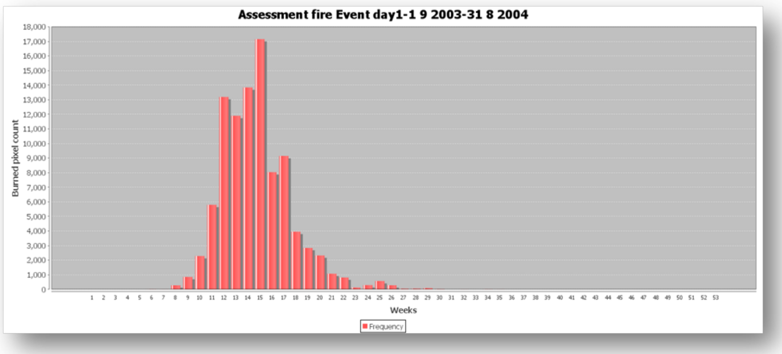


Figure B.21: First burning event weekly distribution in Benin during the fire season 2003- 2004

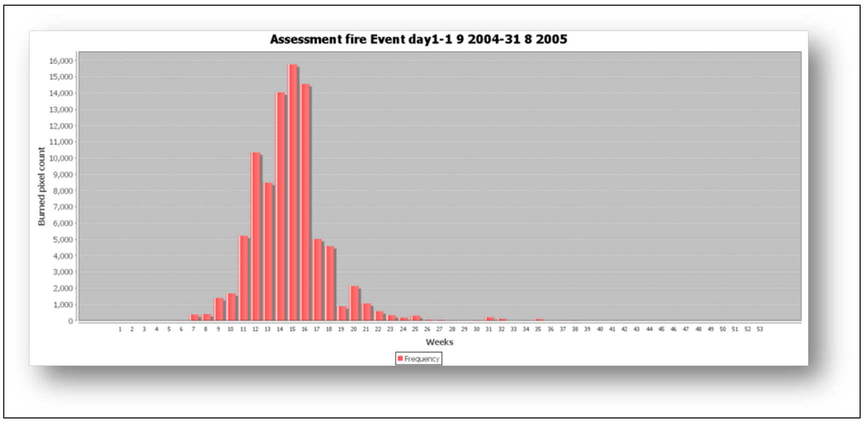


Figure B.22: First burning event weekly distribution in Benin during the fire season 2004- 2005

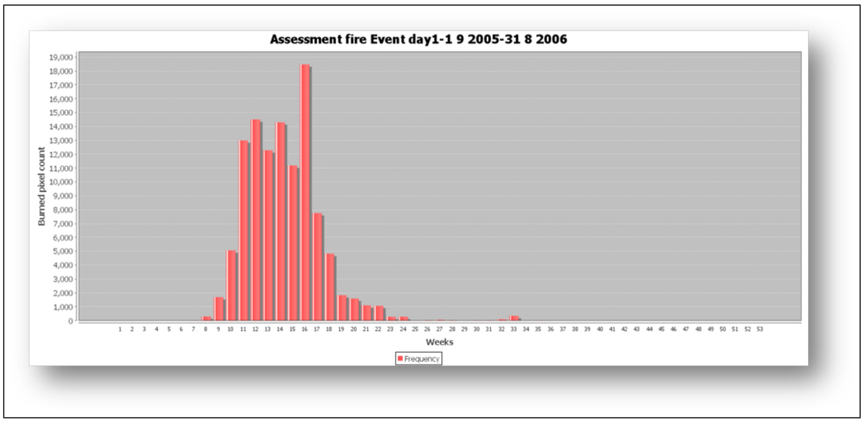


Figure B.23: First burning event weekly distribution in Benin during the fire season 2005- 2006

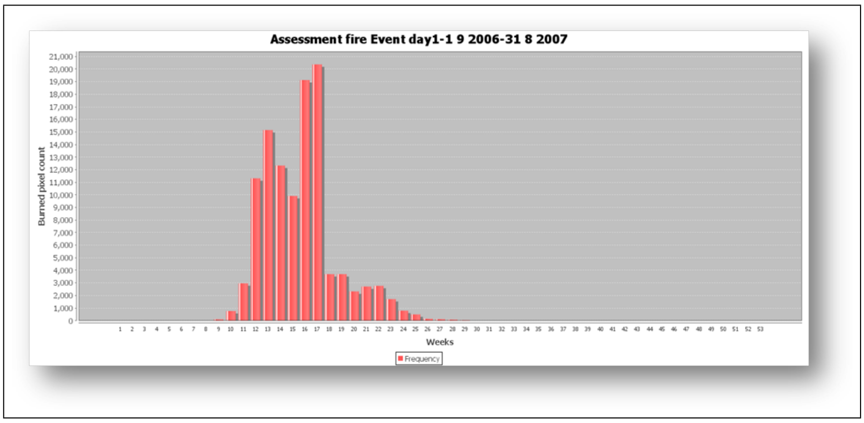


Figure B.24: First burning event weekly distribution in Benin during the fire season 2006- 2007

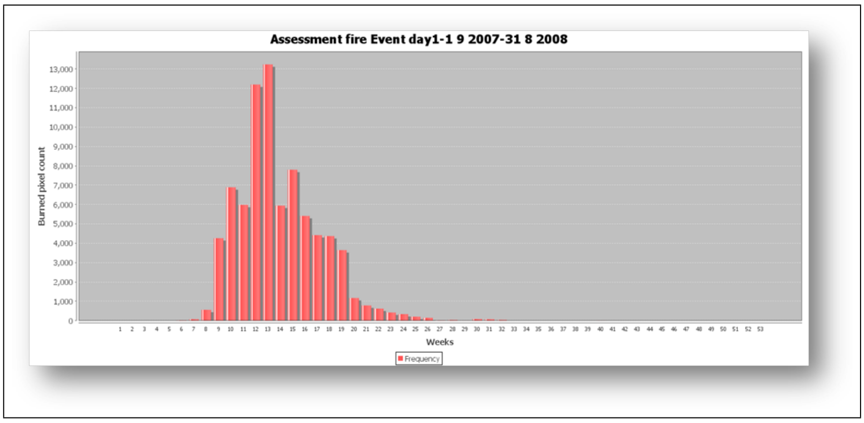


Figure B.25: First burning event weekly distribution in Benin during the fire season 2007- 2008

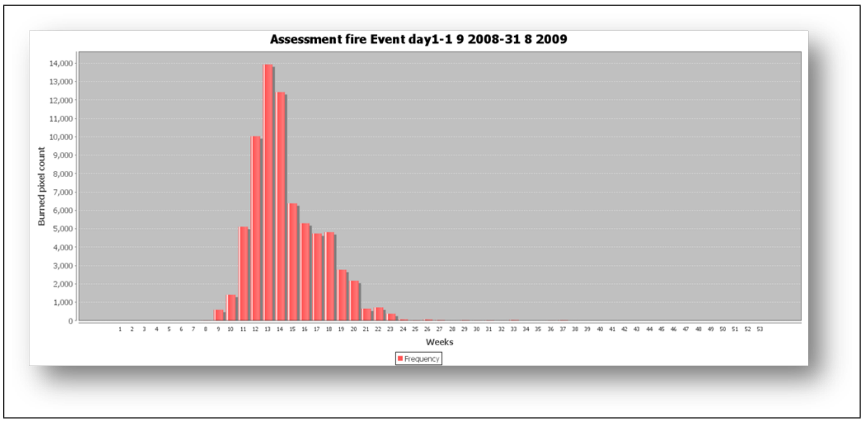


Figure B.26: First burning event weekly distribution in Benin during the fire season 2008- 2009

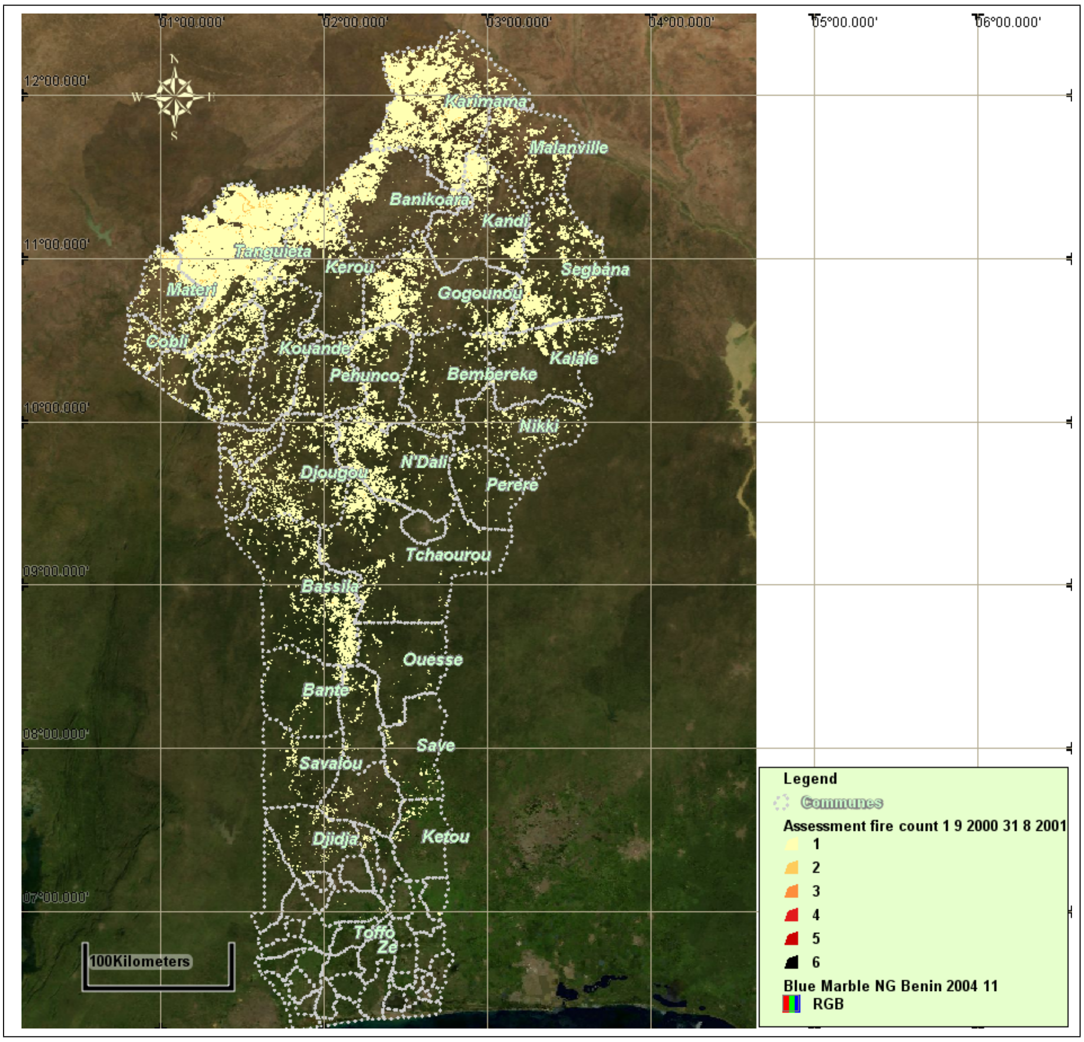


Figure B.27: Spatial distribution of bush fire annual frequency as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2000- 2001. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

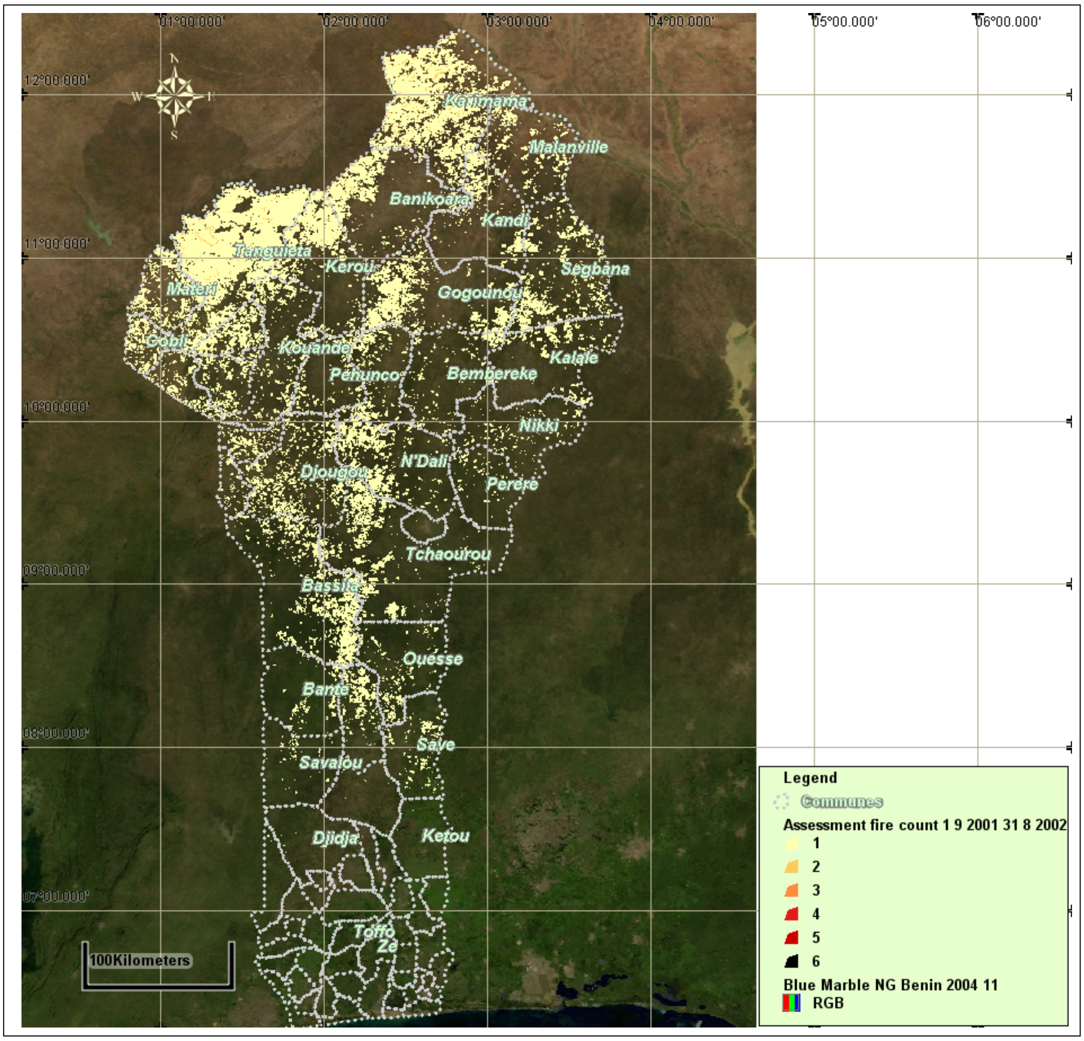


Figure B.28: Spatial distribution of bush fire annual frequency as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2001- 2002. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

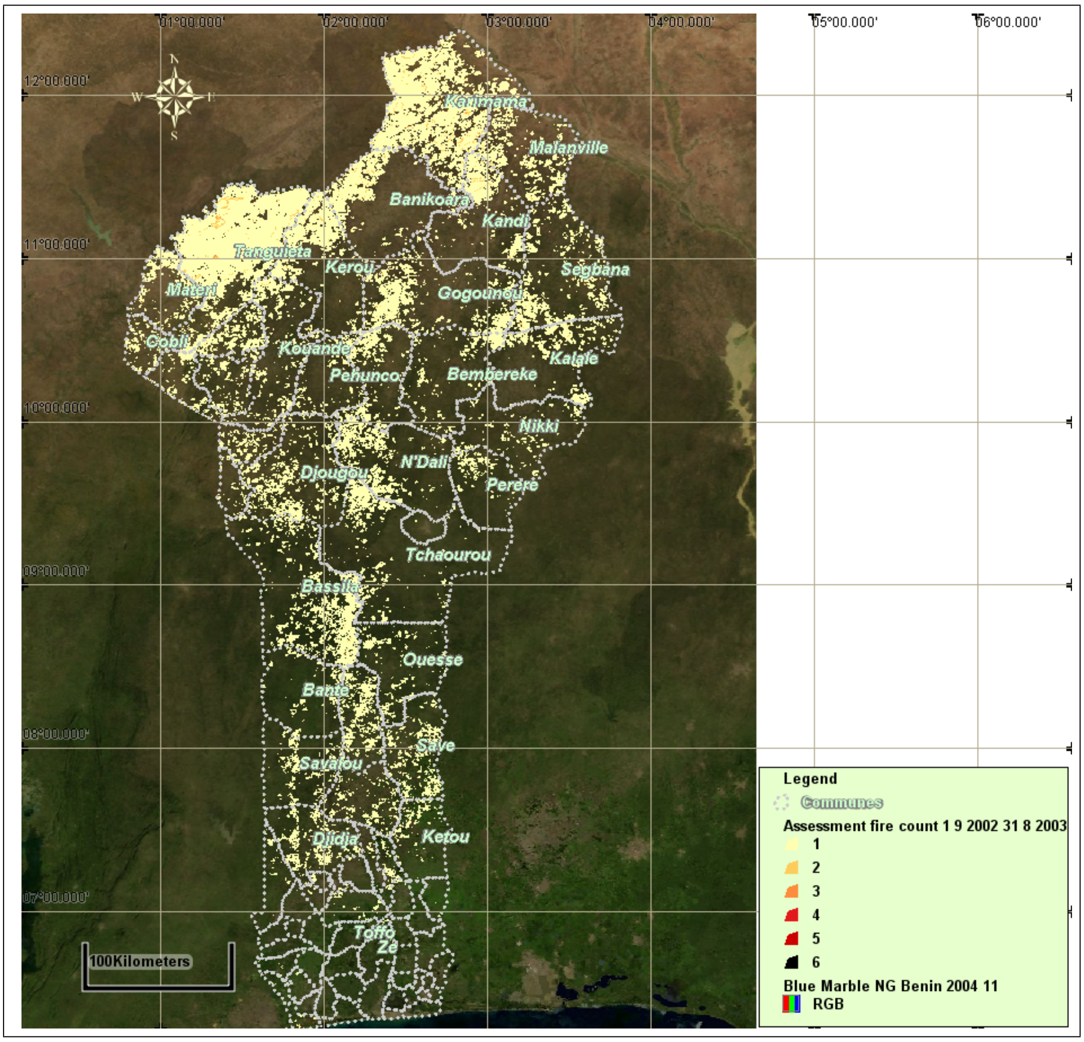


Figure B.29: Spatial distribution of bush fire annual frequency as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2002- 2003. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

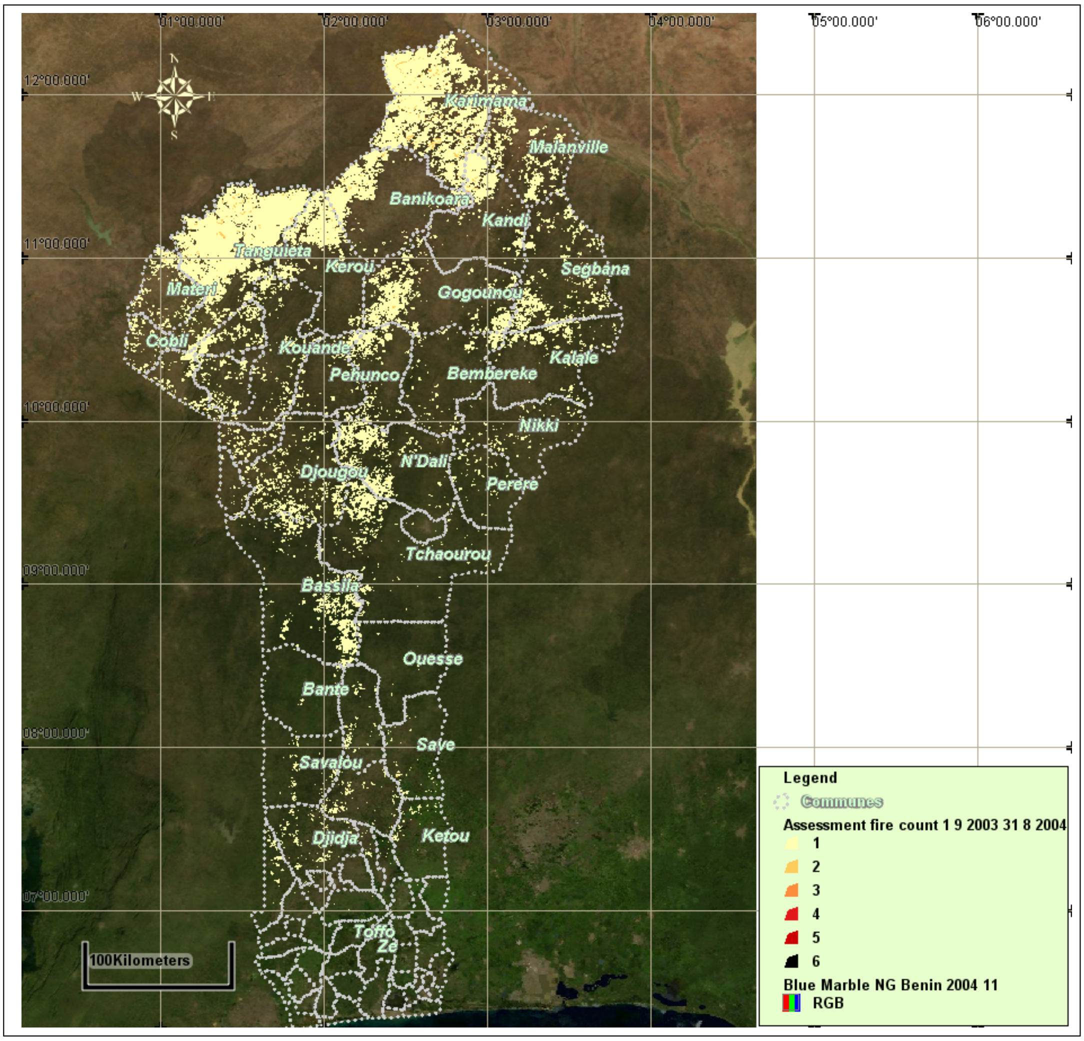


Figure B.30: Spatial distribution of bush fire annual frequency as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2003- 2004. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

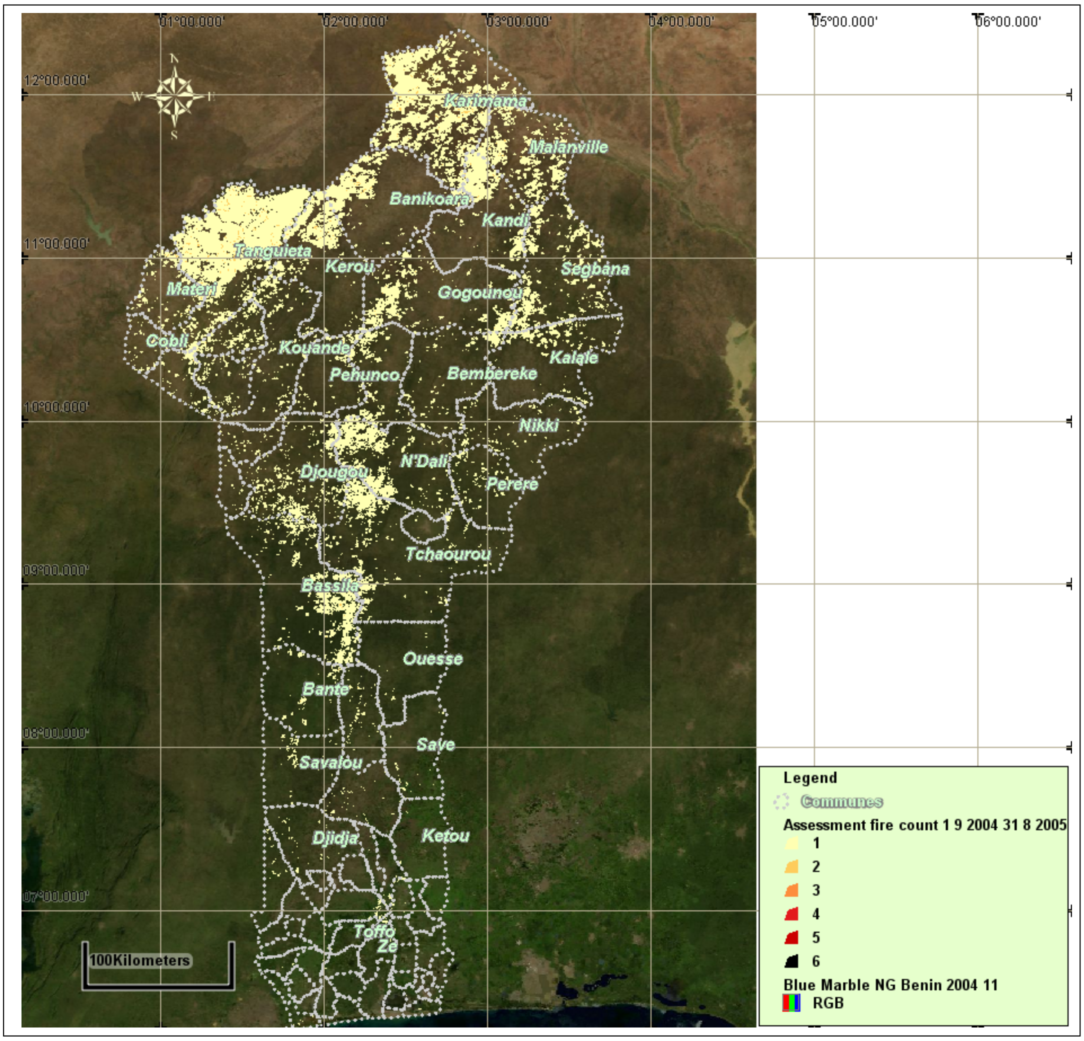


Figure B.31: Spatial distribution of bush fire annual frequency as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2004- 2005. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

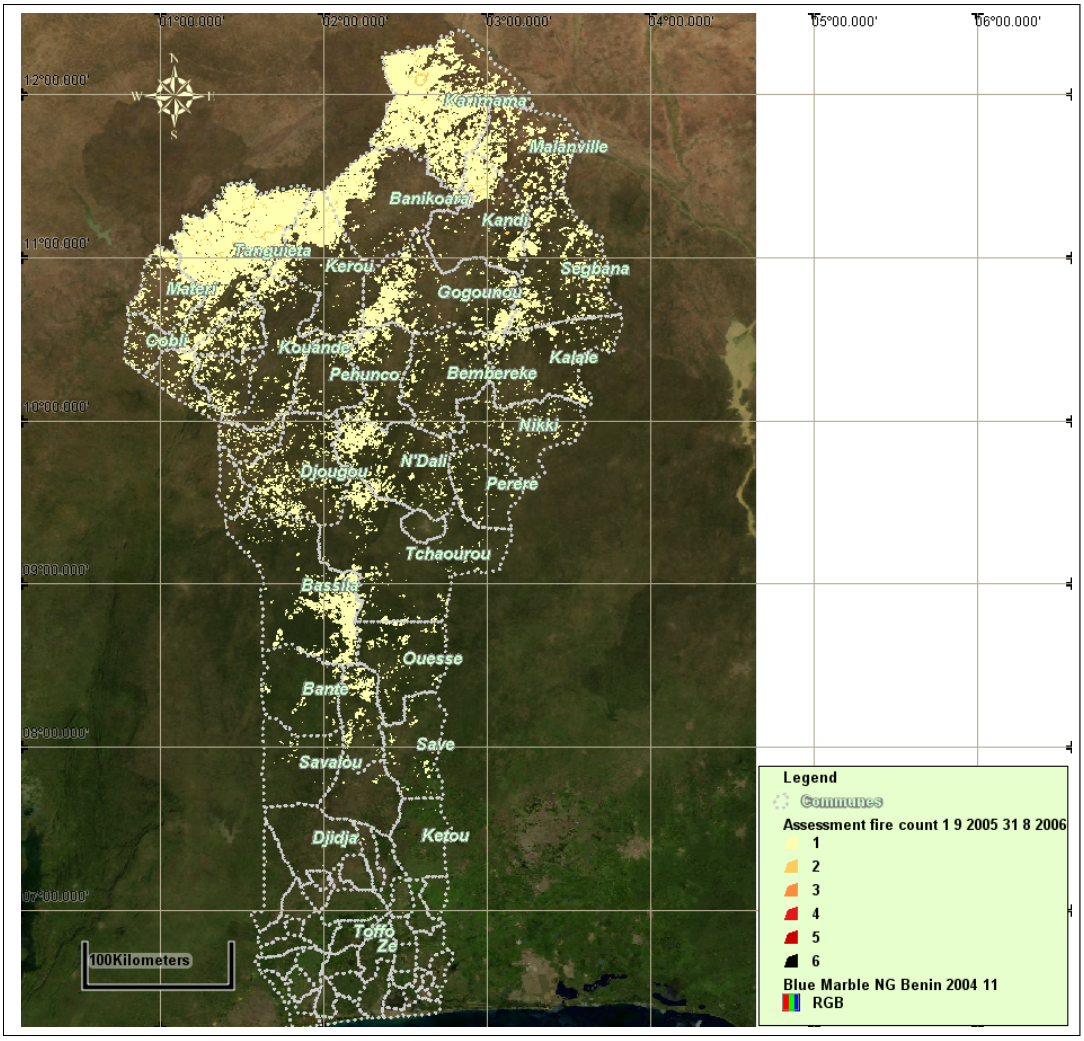


Figure B.32: Spatial distribution of bush fire annual frequency as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2005- 2006. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

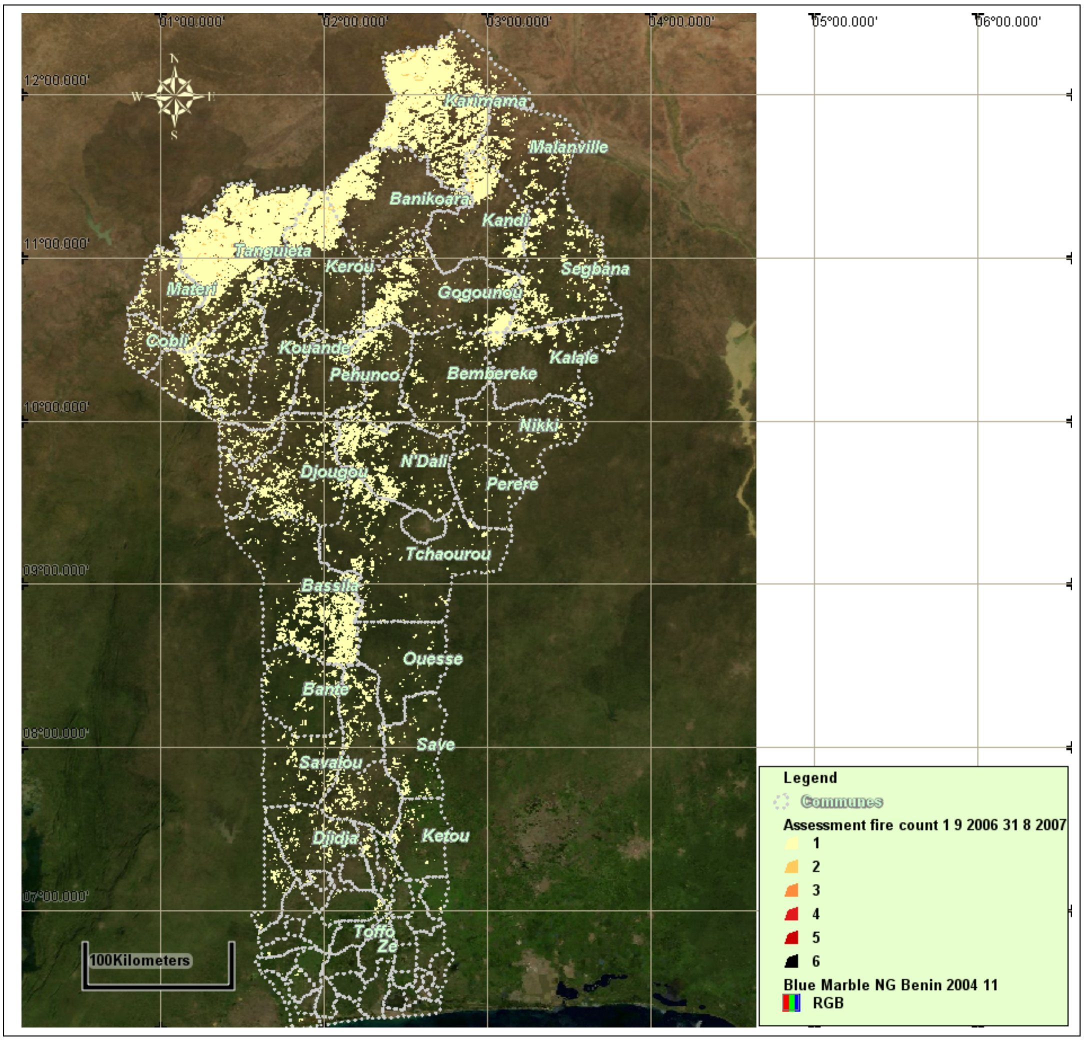


Figure B.33: Spatial distribution of bush fire annual frequency as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2006- 2007. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

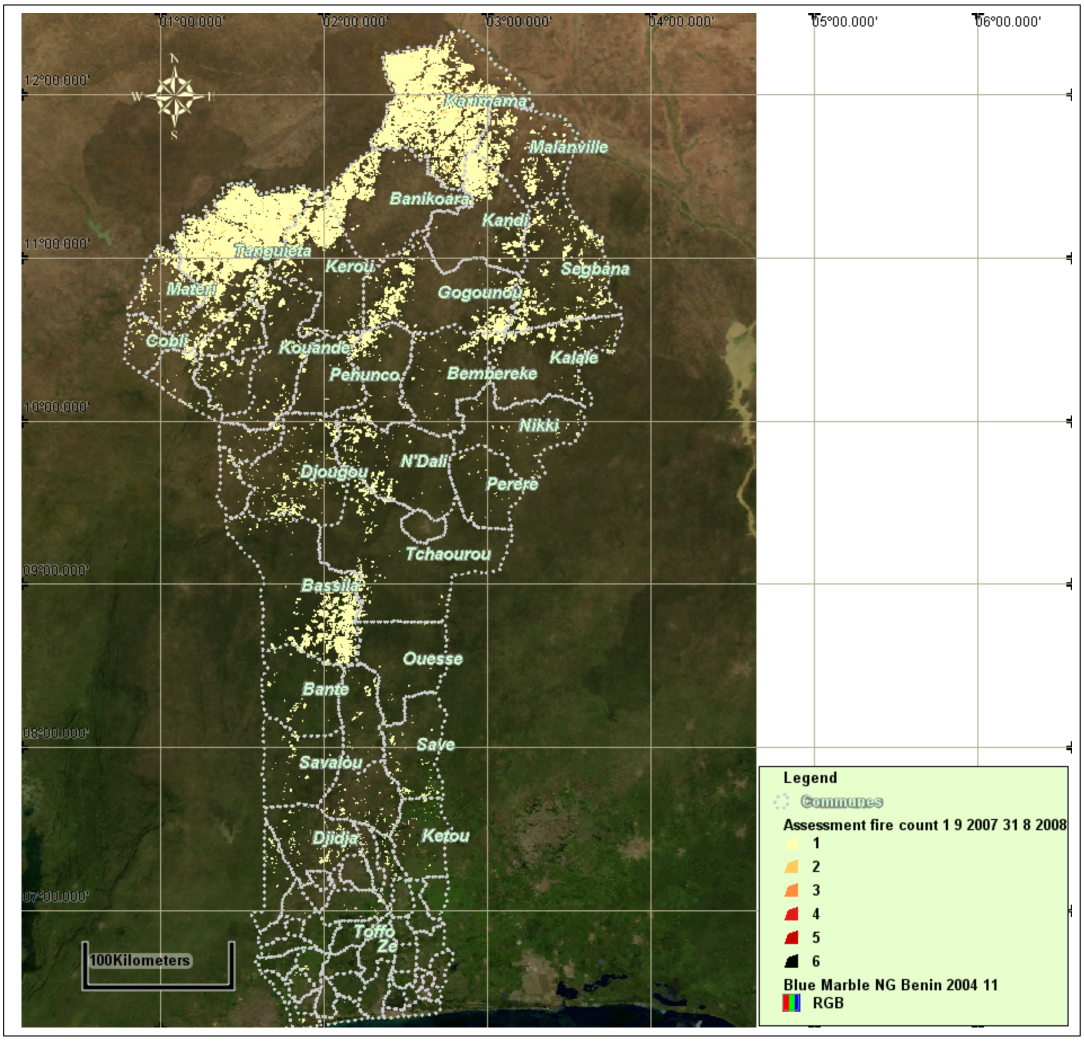


Figure B.34: Spatial distribution of bush fire annual frequency as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2007-2008. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

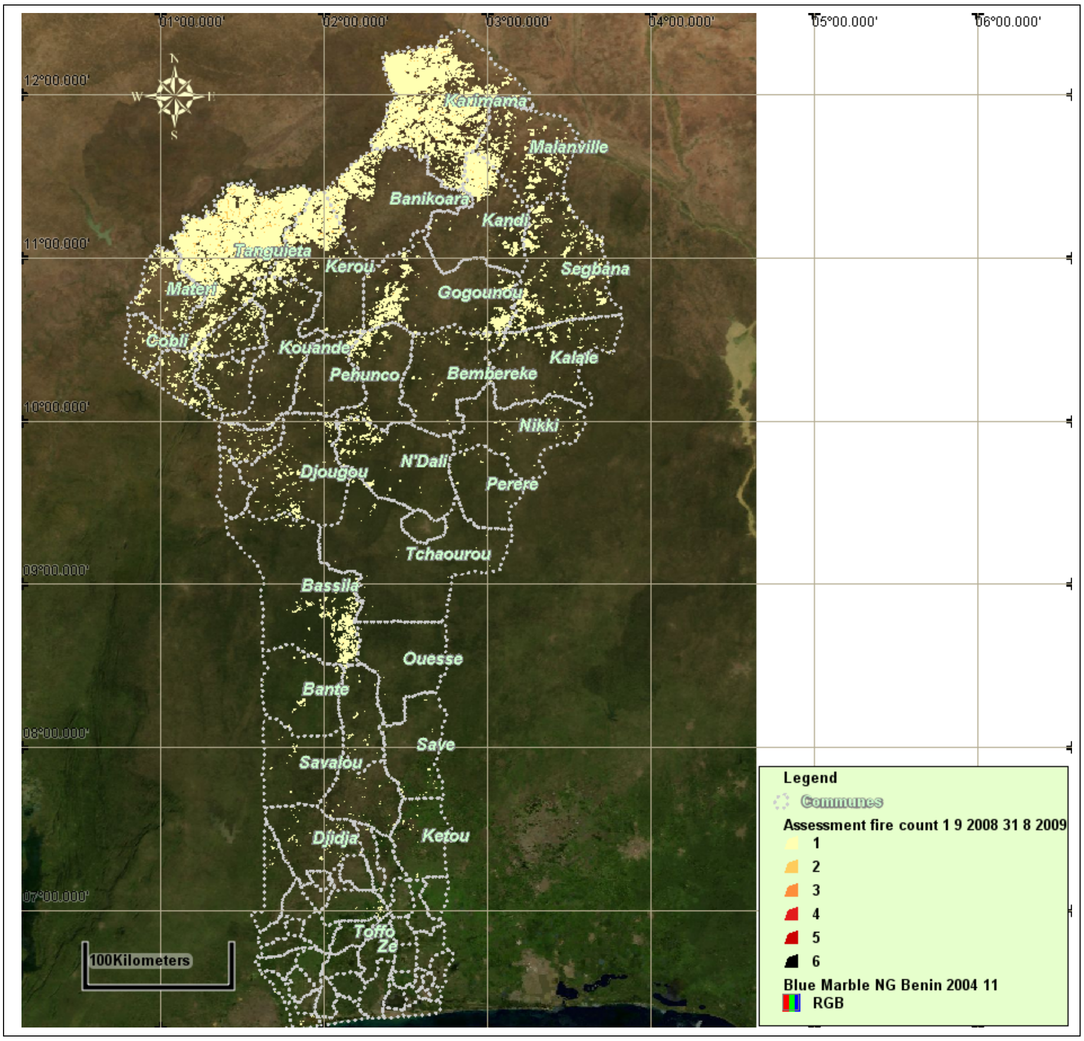


Figure B.35: Spatial distribution of bush fire annual frequency as calculated on the basis of MODIS data using the SDSS FIMAT for the time period 2008- 2009. In background is a true color image from Blue Marble (source: NASA images by Reto Stöckli)

Appendix C
Tables

Table C.1: List of mammals in Pendjari Park(source:Plan dAménagement Participatif et de Gestion de la Réserve de Biosphère de la Pendjari, Décembre 2005)

Scientific name	English name
Acinonyx jubatus	Cheetah
Acomys cahirinus johannis	Spiny mouse
Alcephalus buselaphus	Kongoni (Hartebeest)
Aonyx capensis	African clawless otter
Apodemus sylvaticus	Long-tailed field mouce
Arvicanthis niloticus testicularis	Anstriped grass rat
Atelerix albiventris	African hedgehog
Atilax paludinosus	Marsh mongoose
Canis adustus	Side-striped jackal
Canis aureus	Common jackal
Cephalophus rufilatus	Red-flanked duiker
Cercopithecus aethiops tantalus	Tantalus Monkey
Civettictis civetta	African civet
Cricetomys gambianus	Giant pouched rat
Crocuta crocuta	Spotted hyana
Damaliscus lunatus korrigum	Topi, Tiang, Tsessebe
Epomophorus gambianus	Fruit bat
Erythrocebus patas	Patas Monkey
Euxerus erythropus	Striped ground squirrel
Felis caracal	Caracal
Felis serval	Serval cat
Felis sylvestris libyca	Wild cat
Funiscirius anerythrus	Thomas´s rope squirrel
Galago senegalensis	Senegal galago
Genetta genetta	Common genet
Genetta tigrina	Blotched genet
Heliosciurus gambianus	Gambian sun squirrel
Herpestes ichneumon	Ichneumon mangoose
Herpestes sanguinea	Slender mangoose
Hippopotamus amphibius	Hippopotamus
Hipposideros caffer	Leaf-nosed bat
Hippotragus equinus	Roan antelope

Continued ...

Scientific name	English name
Hystrix cristata	Crested porcupine
Ichneumia albicauda	White-tailed mongoose
Iconyx striata	Zorilla
Kobus ellipsiprymnus	Waterbuck
Kobus kob	Kob
Lemniscomys barbarus	Zebra mouce
Lepus crawshayi (syn. saxatilis)	Scrub hare
Loxodonta africana	African elephant
Lutra maculicollis	Spot-necked otter
Lycaon pictus	Wild dog
Mastomys natalensis	Multimammals rat
Mellivora capensis	Ratel (Honey badger)
Myomys daltoni	Medow rat
Orycteropus afer	Aardvark
Ourebia ourebia	Oribi
Panthera leo	Lion
Panthera pardus	Leopard
Papio anubis	Olive Baboon
Phacochoerus africanus	Common warthog
Procavia capensis	Cape rock hyrax
Redunca redunca	Bohor reedbuck
Smutsia (Manis) gigantea	Giant Pangolin
Sylvicabra grimmia	Bush duiker
Syncerus caffer	African buffalo
Tadarida pumila	Guano bat
Tatera kempi	Tatera gerbil
Taterillus gracilis	Taterillus gerbil
Thryonomys swinderianus	Marsh cane rat
Tragelaphus scriptus	Bushbuck

Appendix D

MODIS Burned Area Algorithm

D.1 Algorithm Background

(After Boschetti et al. (2009))
Burned areas are characterized by deposits of charcoal and ash, removal of vegetation, and alteration of the vegetation structure (Roy et al., 1999). The MODIS algorithm to map burned areas takes advantage of these spectral, temporal, and structural changes. The algorithm detects the approximate date of burning at 500 m by locating the occurrence of rapid changes in daily surface reflectance time series data. It is an improvement on previous methods through the use of a bidirectional reflectance model to deal with angular variations found in satellite data and the use of a statistical measure to detect change probability from a previously observed state (Roy et al., 2005) . The algorithm maps the spatial extent of recent fires only and excludes fires that occurred in previous seasons or years. The bidirectional reflectance model-based change detection algorithm developed for the MCD45 product is a generic change detection method that is applied independently to geolocated pixels over a long time series (weeks to months) of reflectance observations (Roy et al., 2002, 2005). Reflectance sensed within a temporal window of a fixed number of days are used to predict the reflectance on a subsequent day. A statistical measure is used to determine if the difference between the predicted and observed reflectance is a significant change of interest. Rather than attempting to minimize the directional information present in wide field-of-view satellite data by compositing, or by the use of spectral indices, this information is used to model the directional dependence of reflectance. This provides a semi-physically based method to predict change in reflectance from the previous state.

D.2 The Bidirectional Reflectance Model-based Expectation Approach

Methods have been developed to model the BRDF with a limited number of parameters and then to estimate the model parameters from a finite set of remotely sensed observations (Lucht, 2004). The semi-empirical RossThick-LiSparse reciprocal BRDF model is used for the MODIS global burned area product as it performs robustly in the global MODIS BRDF/albedo product (Schaaf et al., 2002). Like other linear kernel-driven models it allows analytical model inversion with an estimate of uncertainty in the model parameters and linear combinations thereof

(Lucht and Roujean, 2000; Lucht and Lewis, 2000). At each geolocated pixel the three parameter RossThick-LiSparse reciprocal BRDF model is inverted against m 7 reflectance observations sensed in a temporal window of n (16) days duration. The BRDF model parameters are used to compute predicted reflectance and uncertainties for the viewing and illumination angles of a subsequent observation. A Z-score is used as a normalized measure related to the probability of the new observation belonging to the same set as that used in the BRDF model inversion:

$$Z_\lambda = \frac{\rho_{new}\left(\lambda,\Omega,\Omega'\right) - \rho\left(\lambda,\Omega,\Omega'\right)}{\varepsilon}$$

$$\varepsilon = \sqrt{\sigma_\lambda^2 + e^2 - \frac{1}{w}}$$

where: Z_λ is the Z-score value,
$\rho_{new}\left(\lambda,\Omega,\Omega'\right)$ is the new reflectance observation,
$\rho\left(\lambda,\Omega,\Omega'\right)$ is the model predicted reflectance at wavelength computed by analytical inversion of the BRDF model against previous reflectance observations,
Ω,Ω' are the viewing and illumination vectors respectively of the new reflectance observation, is a fixed pre-assigned estimate of the noise in $\rho_{new}\left(\lambda,\Omega,\Omega'\right)$ defined by Vermote et al. (2002),
e is the root mean squared of the residuals of the BRDF inversion (used as an estimate of noise in the observations and the lack of ability of the model to fit the measurements), and
w is the 'weight of determination' of $\rho_{new}\left(\lambda,\Omega,\Omega'\right)$ new (Lucht and Roujean, 2000). Z_λ is adaptive to the viewing and illumination angles of the new observation, as well as the angular distribution, amount of noise, and number of observations used in the BRDF inversion. The Z-score is computed for MODIS bands 2 and 5 as these bands are both sensitive to burning and experience a decrease in reflectance post-fire. A new observation is considered as a burn candidate if:
$(Z_{band_2} < -Z_{thresh})$ OR $(Z_{band5} <$ -Z_{thresh}

where:
Z_{band} is the Z-score defined (1) and Z_{thresh} is a fixed wavelength independent threshold
and if:

$$\rho\left(\lambda_{band5},\Omega,\Omega'\right) - \rho\left(\lambda_{band7},\Omega,\Omega'\right) > \rho_{new}\left(\lambda_{band5},\Omega,\Omega'\right) - \rho\rho_{new}\left(\lambda_{band7},\Omega,\Omega'\right)$$

(3) AND

$$\rho\left(\lambda_{band2},\Omega,\Omega'\right) - \rho_{new}\left(\lambda_{band7},\Omega,\Omega'\right) > \rho_{new}\left(\lambda_{band2},\Omega,\Omega'\right) - \rho\rho_{new}\left(\lambda_{band7},\Omega,\Omega'\right)$$

where $\rho_{new}\left(\lambda,\Omega,\Omega'\right)$ new is the new reflectance observation and $\rho\left(\lambda,\Omega,\Omega'\right)$ is the model predicted reflectance computed by analytical inversion of the BRDF model against m$\geq$ 7 previous reflectance observations. The justification for equation (3) is that burning causes a reduction in band 2 and 5 reflectance but less change in band 7 reflectance, whereas persistent cloud, shadow, or soil moisture changes would have a similar effect in both bands. Band 2 helps to remove changes associated with increasing plant water content which is negatively related to band 5 and 7 reflectance but not band 2 reflectance (Zarco-Tejada et al., 2003). In this work $Z_thresh = 3.0$ to detect only those reflectance changes that fall outside of the expected reflectance variation modeled from previous values (the probability that Z < -3.0 is

0.0013).

D.3 Temporal Implementation

The computation (equations 1-3) is repeated independently for each geolocated pixel, moving through the reflectance time series in daily steps to detect change. A temporal constraint is used to differentiate between temporary changes, such as shadows, undetected residual clouds, soil moisture changes and data artifacts, that pass (1) (3) from fire-affected areas that have persistently lower post-fire reflectance. Gaps in the reflectance time series, for example due to cloud cover or bad quality input data, reduce the temporal frequency of Z-score calculations as they reduce the number of observations available for prediction and the number of windows that have sufficient observations for BRDF inversion. To reduce the impact of gaps, the duration of the BRDF inversion window is allowed to increase and the Z-score is computed not just for the subsequent day but for several subsequent days. The duration of the BRDF inversion window is allowed to increase, from a minimum of n = 16 days up to a maximum of (n + nextra) days, until there are at least 7 observations. When there are fewer than 7 observations no inversion is performed. In this way, more BRDF inversions may be performed in the presence of missing data, providing more opportunities for detecting burning events. At each window containing 7 or more observations the BRDF parameters are used to compute Z-scores for the non-missing observations sensed on the following S_{search} days. If within the following S_{search} days a burn candidate is found, i.e. criteria (1) - (3) are met, then the Z-scores continue to be computed for S_{test} days after the first burn candidate. For each inversion window, the day that the first burn candidate was detected (Day_{first}), the maximum of its band 2 and 5 Z-scores (Z_{first}), and the total number of observations over the subsequent S_{test} days that were considered (N_{used}) and detected as burned (N_{pass}), are derived. Different Day_{first} candidates may be detected due to sensitivity of the adaptive window duration and multi-date prediction to gaps in the time series. In addition, the same geolocated pixel may burn on separate dates. The results from the different inversion windows are ranked with respect to N_{pass} and then N_{used} to provide results in order of the most evidence of persistent burning. If there are results with equal N_{pass} and N_{used} values then the one with the greatest Z_{first} is ranked as more persistent. Searching both forward and backward in time allows burn candidates to be detected in the S_{search} days preceding or following periods of persistently missing data. This also allows burn candidates to be detected in the first and last S_{search} days of the time series. Results for the forward and backward directions are derived independently. When searching backward in time, an increase in reflectance in the appropriate MODIS bands is searched for rather than a decrease in reflectance.

D.3.1 Iterative Procedure for Identification of Burned Candidates

The global algorithm attempts to reduce errors of commission by selecting only burned pixels where there are burn candidates that provide persistent evidence of fire occurrence. As the measured persistence varies depending on gaps in the reflectance time series and the timing of the fire relative to non-missing data, an iterative rather than simple thresholding approach is used. Burn candidates found in both the forward and backward directions are considered. First, burned pixels are selected as occurring on Day_{first} if:
$N_{pass} \geq 3$ AND $(N_{pass}/N_{used}) \geq 0.5$ AND $N_{inv} \geq 3$ (4) In this way only candidates are selected, regardless of the direction of the detection, where at least 50% of the observations considered over the subsequent S_{test} days are detected as burned and at least 3 inversions (N_{inv}) are used for the consistency test. If several burn candidates are found at a given pixel, then they are considered in order of decreasing evidence of persistent burning and the first one that passes condition (4) is selected. If forward and backward search results have equal persistence then the forward direction results are given precedence. In cloudy regions, even confidently detected burn candidates might have insufficient data for 3 inversions within the timeframe of the consistency test. As a consequence, if and only if backward and forward predict the same change, burned pixels are selected, regardless of N_{inv} using the less restrictive test: $N_{pass} \geq 3$ AND $(N_{pass}/N_{used}) \geq 0.5$(5) Second, rather than discard burn candidates that are likely burned but do not pass conditions (4) and (5) due to insufficient observations, they are considered using less restrictive criteria than (4) or (5) in an iterative search method. This method is based on the principle that there is increasing expectation of a burn occurring in pixels neighboring confidently detected burns ((Roy et al., 2002)). In this search procedure, the burn candidates selected by (4) and (5) are considered seed pixels. In the first set of iterations, non-seed pixels where burn candidates were detected that did not pass conditions (4) or (5) are accepted as burned if they have two or more adjacent seed neighbors and if:

$Day_{first} - Day_{first\_seed} < N_{gap}$ AND $N_{pass} \geq 2$ AND $(N_{pass}/N_{used}) \geq 0.25$ (6) where Day_{first}, N_{pass}, and N_{used} are the values for the burn candidate that did not pass conditions (4) or (5) and Day_{first_seed} is the mean Day_{first} value of the two to eight adjacent seed pixels. The N_{gap} constraint ensures that only burn candidates that occur temporally as well as spatially close to the neighboring seed pixels are considered. This procedure is repeated in an exhaustive iterative manner with the pixels that passed condition (6) being considered as seeds for the next iteration until no more burn candidates that pass (6) can be included. As with condition (4), if several burn candidates are found at a given pixel then they are considered in order of decreasing evidence of persistent burning until (6) is met. Again, if forward and backward search results have equal persistence then the forward direction results are given precedence. In the second part of the procedure, the residual burn candidates not selected in the previous steps are considered if at least three neighbors have been selected. The average day of burning of the neighbors is computed, and the pixel is accepted if the backward

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Erklärung

Hiermit versichere ich, dass ich die vorliegende Dissertation selbständig angefertigt und die benutzen Quellen und Hilfsmittel vollständig angegeben habe. Sie wurde an keiner anderen Hochschule als Dissertation eingereicht und wurde auch nicht an anderer Stelle veröffentlicht.

Bonn, February 3, 2011 **Côme Agossa Linsoussi**