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ANALYSIS OF VELDFIRE INCIDENTS IN MAKONI AND CHIMANIMANI DISTRICTS OF ZIMBABWE USING GIS, REMOTE SENSING AND PUBLIC DOMAIN DATA

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ABSTRACT

This study examines the application of public domain data and remote sensing using the Moderate-Resolution Imaging Spectrometer (MODIS) instrument in the detection and monitoring of fire incidents in Zimbabwe with particular reference to Chimanimani and Makoni districts of Manicaland Province. The assessment, mapping, and analysis of the fire incidents were undertaken done using the Arc View Geographical Information Systems software with spatial analysis and extensions. The study revealed that in 2005, a total of 1,436 fire incidents were detected in the two districts, with 159 in the communal areas and the rest in the arms and exotic forest plantations. In 2006, the number of fire incidents declined to 490. The majority of the fires were detected in August and September due to the lack of rainfall during these months and the high summer temperatures that provide the suitable conditions for ignition. It is recommended that there is a need to develop a framework for the integration of GIS, Remote Sensing, and Public Domain data in veld-fire assessment.

Keywords: Geographical Information Systems; Remote Sensing; Public Domain Data; veld-fire; Moderate-Resolution Imaging Spectrometer (MODIS)

INTRODUCTION

The judicious use of Geographical Information Systems, Remote Sensing products, and public domain data in veld-fire management is vital for the pre-fire season and fire season planning, prediction and decision making at reduced costs since these technologies allow for better allocation of limited financial and human resources in institutions involved in fire prevention and management in Zimbabwe. This is an essential pre-requisite for sustainable development (Andreae, 1997; Benhardsen, 1996; Li, Khananian and Fraser 2 000a; Li Khananian 2000b DeMers, 1999; Escobar, Hunter, Bishop, Zerger 2003; Fraser & Cihlar, 2000).

Chimanimani district was selected for this analysis because of its ecological uniqueness and its importance to the economy of Zimbabwe. Since 2005, Chimanimani has been one of the districts in Manicaland with the highest number of fire incidents and damage to its property. It was, thus, an interesting area for this assessment since, in 2006, the government, through the Ministry of Environment and Tourism, the Environmental Management Agency, and the local timber companies, teamed up and launched the National Fire Strategy in Chimanimani. Indirectly, this assessment can be taken as a barometer of the effectiveness of fire awareness campaigns. Makoni was of interest because it is one of the relatively drier districts in Manicaland and it recorded high fire incidents in the 2006 fire season.

Sub-Saharan Africa experiences extensive biomass degradation with approximately 1.7 million km^2 (17 % of the land area) burns annually. South of the equator is host to tropical savannas that are characterized by a unique co-existence of tree and herbaceous species (Chidamayo, 1997; Ganz, Fisher and Moore 2003; Gregoire, 2003). Terrestrial savanna ecosystems, though shifting mosaics, are perceived to be fire tolerant because of their inherent ability to regenerate through coppicing and seeds. Extensive biomass burning is, thus, a core component of the ecological-disturbance regimes affecting these savanna ecosystems. In Southern Africa, fire is perceived ambiguously since there is tension between fire as a crucial process in certain ecosystems and fire events as a threat to infrastructure and life. In both cases, spatio-temporal awareness of the likelihood of fire, fire occurrence and fire behavior is key to appropriate intervention. The fires occur due to both natural and anthropogenic causes, primarily lightning and land management (Barbosa, Stroppiana, Gregoire and Pereira, 1999; F.A.O, 1999; F.A.O, 2001; F.A.O, 2003; W.W.F, 2001)

The study of veld-fire dynamics using remote sensing and public domain data, which is data or information obtained both from the local community and the district officers, is therefore central to the determination of the economic turn around of the development agenda of Zimbabwe. The Environmental Management Agency of Zimbabwe, the focal point of all environmental issues in the country, has focused on fire prevention, but because of financial and resource constraints, the work of fire prevention and detection has been severely constrained and ineffective. It is, therefore, imperative to explore other avenues that will assist in spatial mapping and detection of bushfires at least-cost. This necessitates the use of public domain data, remote sensing data, such as Moderate-Resolution Imaging Spectrometer (MODIS), and Geographic Information Systems (GIS). The next trophic level of GIS and Remote sensing application involves the incorporation of Normalized Differentiation Vegetation Index (NDVI) as a proxy of vegetation damage, which this research did not explore because of time constraints.

In the past few years, widespread fire incidents in Chimanimani district caused damage to property and terrestrial ecosystems due to lack of fire awareness campaigns owing to limited financial and human resources. The Provincial Fire Strategy noted that in the past few years, Manicaland experienced widespread fires that affected most parts of the district with the most affected being plantations, resettlement areas, and communal areas. Affected plantation hectarage between the years of 2005 and 2009 was at least 6 703 hectares. The National Fire Protection Strategy launched in Chimanimani is thus a drive to respond to the veld-fire problem and proactively prevent the occurrence of fires. It is in this view of the lack of application of remote sensing instruments, such as MODIS, in combination with public data that the researchers conceptualized carrying out an assessment of the fire season by using public domain data integrated with Remote Sensing and GIS.

This study focused on the two districts of Chimanimani and Makoni in the Manicaland Province of Zimbabwe, as shown in Fig. 1. Chimanimani is located in the southeastern part of Zimbabwe and covers an area of 3353 km^2. It is divided into 23 administrative wards with an average household size of 4.4 and a population of 115,250. The Makoni district is located in the northeastern part of Zimbabwe and has a total population of 151 596 people (C.S.O., 2002).

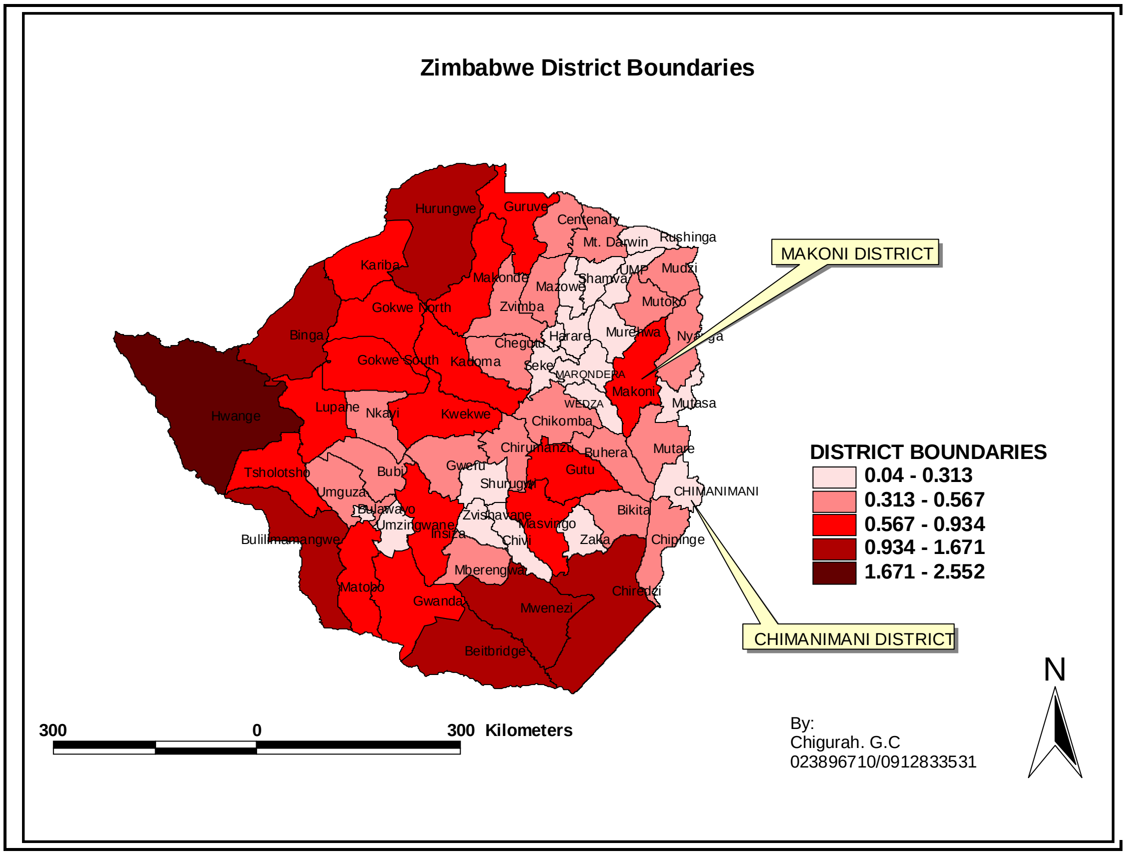

Fig 1: Map showing the districts of Chimanimani and Makoni.

The aim of the study is to develop a framework for the integration of Geographical Information Systems, Remote Sensing data, and public domain data in veld-fire assessment, monitoring, and analysis in the country. This would enable the environmental planner to spatially map veld-fire incidence using GIS Arc View 3.2 a software and MODIS. Specific objectives include identifying imperative methods that will assist in spatial mapping and detection of bushfires at the least cost, assessing the effectiveness of remote sensing, and public domain data in the monitoring and detection of fire incidents and, hence, suggesting a suitable data infrastructure to develop and support the use of GIS and remote sensing for fire management.

METHODOLOGY

Analysis Operations Conducted

The assessment, mapping, and analysis of the Chimanimani and Makoni fire incidents was undertaken using Arc View 3.2 Geographical Information Systems Software with spatial analyst and extensions and this involved buffering and overlay operations. A buffer zone is an area of a specified width that is drawn on one or more map elements. For example, to define a forest area where logging is not permitted, a 200 m buffer zone can be drawn around dust roads. Complex analysis may require values to be calculated for a large number of point locations and may involve overlay operations with multiple data layers. A 200 m buffer zone to assess the fire recurrence interval was used. Standard overlay operators were used and these make use of two or more input data layers, which are geo-referenced in the same system and overlapped in the study area. The principle of the spatial overlay was to compare the characteristics of the same location on both data layers and produce a new characteristic of each location in the ultimate levels. Simple operations are performed, for example laying a ward boundary map for Chimanimani over a map of local land-use intensity for the same area. Since the data used originated from different sources, the data was standardized using the following parameters:

Projection:	UTM 1927
Spheroid:	Clark 1880
Universal Transverse Mercator Zone:	36
Central Meridian:	33
Scale Factor:	0.996
False Easting:	500,000
False Northing:	0
Distance Units:	Meters

Other primary data collection methods involved interviews and questionnaire surveys that were directed at fire and environmental officers from the two districts. The major advantage of these interviews was that an opportunity was offered for conveying information while getting an immediate response.

RESULTS AND DISCUSSION

The 2006 and post-2006 fire seasons saw a more proactive stance being taken by the Environmental Management Agency in a bid to stem the tide of destruction and incidence of veld-fire or Bushfires. The launch of the National Fire Prevention strategy in the Manicaland province was a landmark occasion not only for the whole nation, but also the province. The National Fire Prevention Strategy ushered in a ‘new’ fire prevention and management approach, which, in part, saw the collection of fire statistics in the Province by the Environmental Management Agency. Below is a cumulative fire report for 2005 to 2006.

Spatial distribution of fire incidents in Chimanimani district

Wild fires start early on in the dry season, in about May or June. Most fires, however, occur between August and October and sometimes in November. The exact time of year at which fires start and finish depends on the past rainy season and the start of the rains in the current season. For Chimanimani, in 2005, most of the fires were located in and around forest plantations of the Charter Estate, Martin Forest, and Gwindingwi Forests (Fig 2). Availability of excess burning fuel from dry tree leaves and underlying grass gives rise to early ignition, hence promoting higher incidents of fire outbreaks. Land use practices in communal lands do not produce favorable conditions for fire outbreaks. Practices such as cultivation, animal grazing, and cutting down of trees by the community for firewood reduce the amount of dead dry fuel on the ground, thereby reducing the possibility of major fire outbreaks. Wards such as Nyanyadzi, Chakohwa, Changazi, Guune, and Mhakwe did not experience any detectable fire outbreaks. Shinja experienced 6 outbreaks; Rupise experienced 2 outbreaks; Mhandarume experienced 1 outbreak; Chikwakwa experienced 2 outbreaks; Chikukwa experienced 1 outbreak; Ngorima A and B both experienced 14 outbreaks; Biriri experienced 3 outbreaks; Nyahode Resettlement experienced and Bumha (Shinja Resettlement) recorded he highest outbreaks of incidents due to the availability of burnt fuels because of their intact forests and few human and animal tracks that can act as natural fireguards in the event of a fire outbreak.

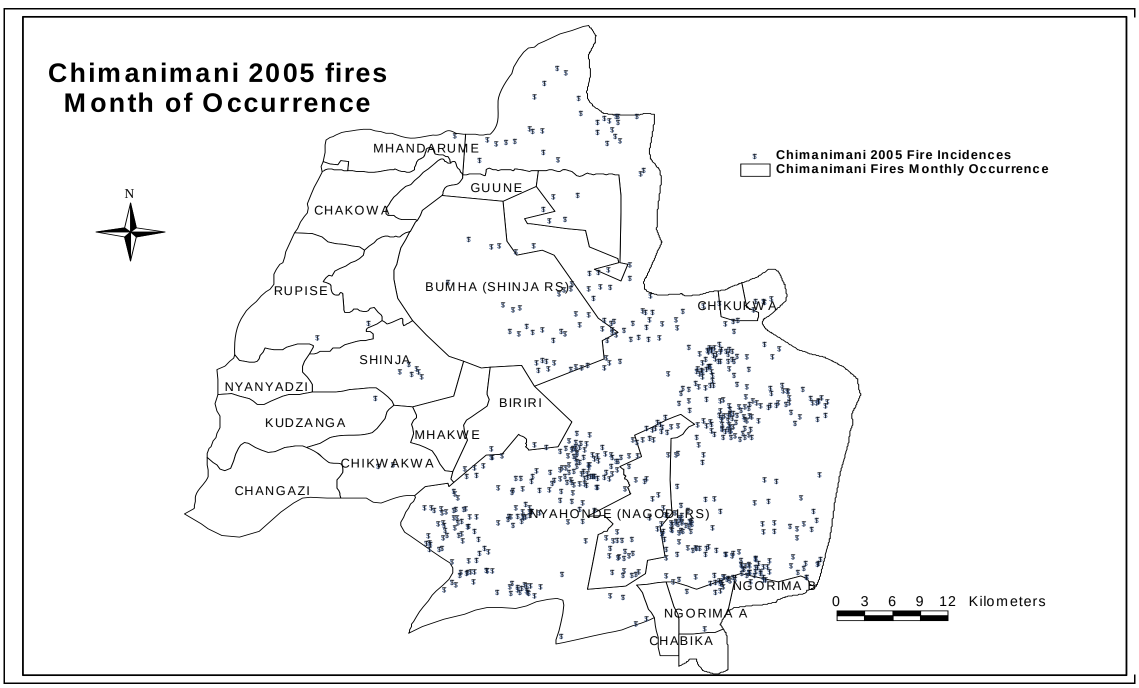

Fig 2: The fire incidents for Chimanimani District

A total of 112 incidents were detected in the communal and resettlement areas, accounting for only 16.16% of the total incidents detected in 2005. Nyahode and Bumha Resettlement areas recorded a total of 89 major fire outbreaks constituting

12.8% of the total detected fires for 2005. The most affected areas were Charter Forest Estate, Tilbury Forest, Gwindingwi Forest, Martin Forest, Tarka Forest, and Cashel where a total of 581 of the 693 fires were detected. These constituted 83.84% of the detected fires throughout the district for 2005.

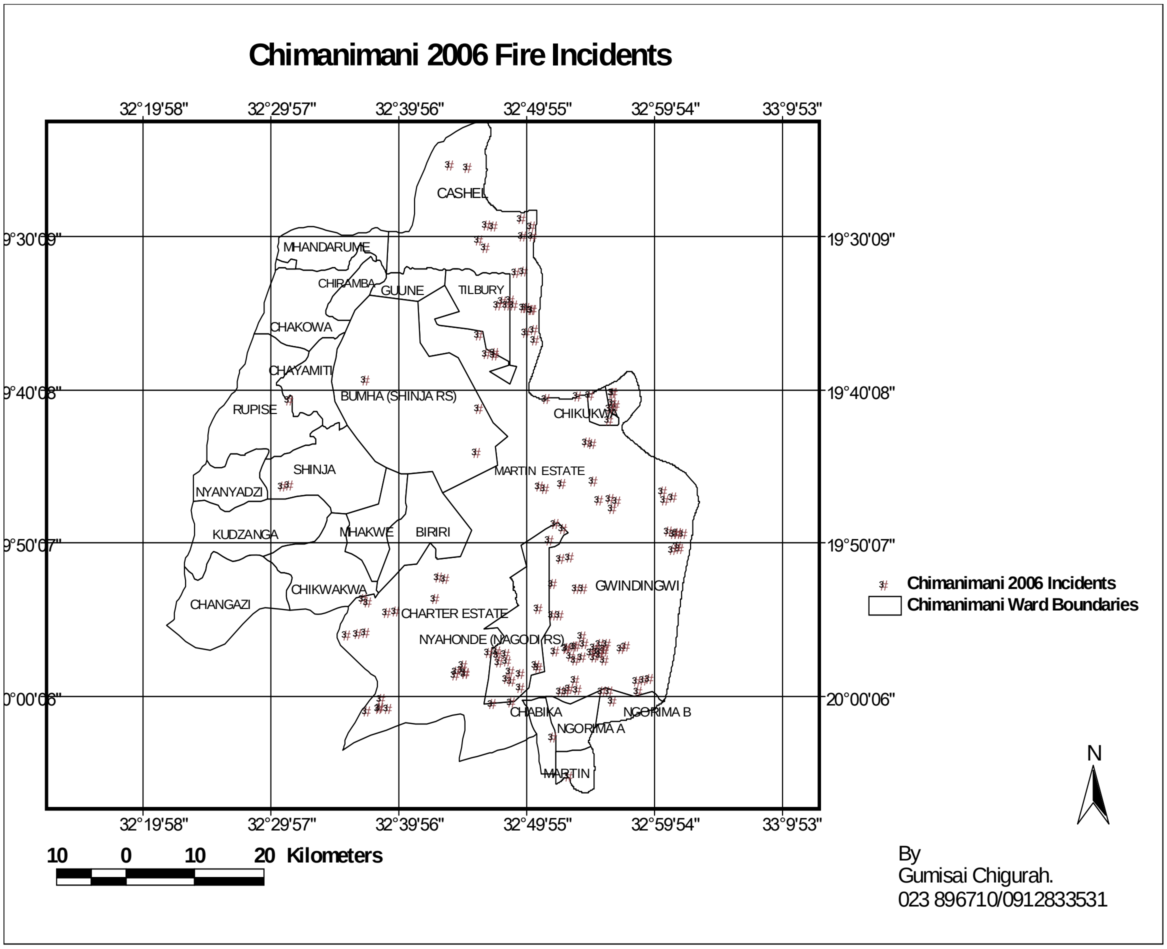

Fig 3: Chimanimani District Map showing Locations of 2006 Fire Incidents.

In 2006, Shinja, Chayamiti, Bumha, Manyuseni, Chabika, Ngorima B, Nyahode, and Chikukwa recorded 2; 1; 3; 1; 13; 20; and 6 fire outbreaks, respectively, for 2006. Rupise, Kudyanda, Nyanyadzi, Chakohwa, Chiramba, Guune, Changazi, Chikwakwa, Mhakwe, Biriri, Ngorima A, and Mhandarume did not experience any detectable fires in 2006, as shown in Fig 3. The communal and resettlement areas had a total of 37 fire outbreaks, with the Nyahode Resettlement area recording the highest detection of 20 incidents, followed by Chikukwa ward, which had 6 incidents. The incidents that were detected in the communal and resettlement areas constituted 24.83%, while the remaining 75.168% were detected in exotic forest plantations.

Spatial distribution of Fire Incidents in Makoni district

Figure 4 shows the location of different fire incidents that were detected in the Makoni District in 2005 and 2006. In 2005, the district recorded 743 incidents of major fire outbreaks and in 2006 it recorded 341 detections of fire outbreaks. In 2005, 47 incidents were detected in Gweza, Rongwe, Tsagura, Dowa, Ngome, Nyamagura, Matotwe, Dumbamamwe, Batanai, and Chitangazuva and the remaining 696 were detected in the surrounding farms. Table 1 shows the fire incidents that were detected in the communal areas and the surrounding farms of Makoni District in 2005.

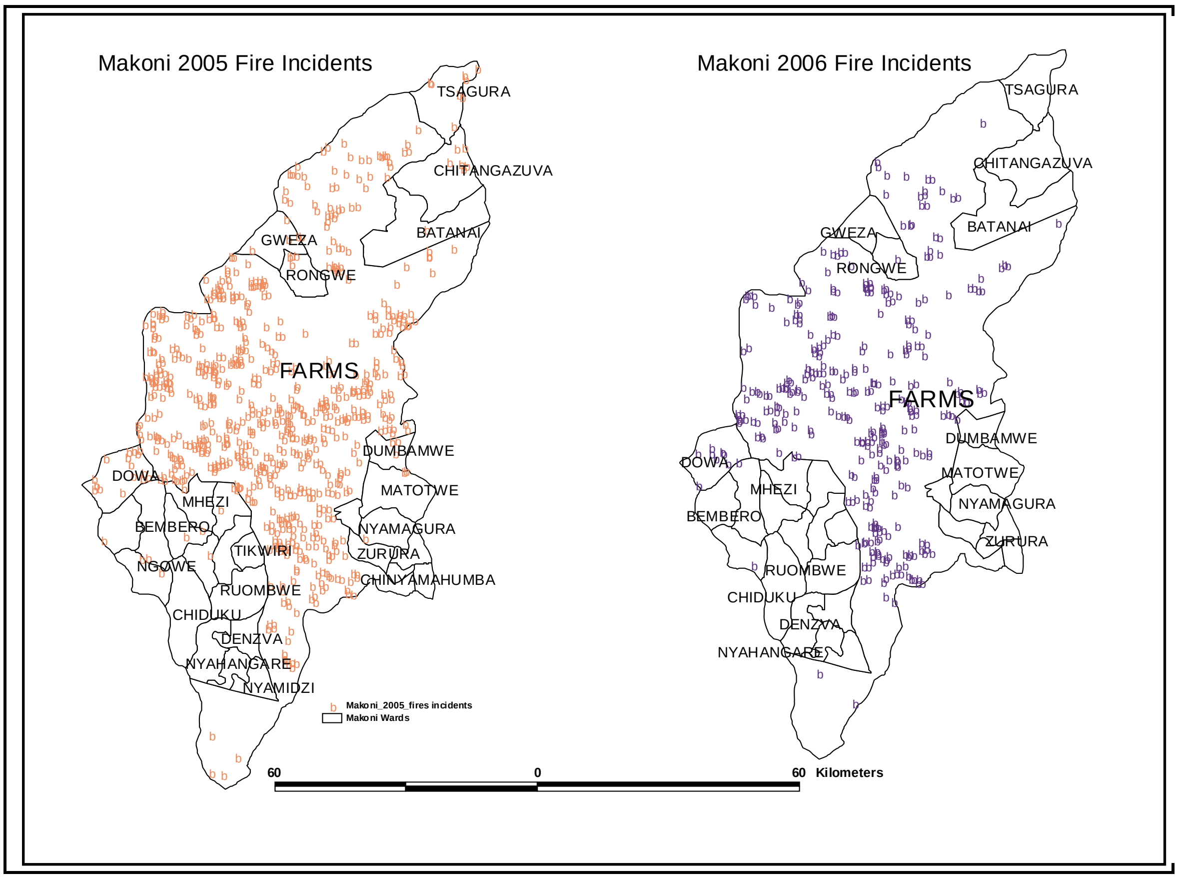

Fig 4 Map of Makoni District showing location of 2005 and 2006 fire incidents.

Batanai recorded 4 outbreaks; Chitangazura recorded 6 outbreaks; Dumbamwe recorded 3 outbreaks; Gweza recorded 4 outbreaks; Matotwe recorded 2 outbreaks; Nyamagura recorded 1 outbreak; Ngome recorded 3 outbreaks; Rongwe recorded 4 outbreaks; Dowa recorded 15 outbreaks; and Tsagura recorded 8 outbreaks, as indicated in Table 2. The incidents that were detected in the communal areas accounted for 6.33% of the total incidents detected in Makoni District in 2005. The remaining 93.67% were detected in the surrounding farms. Chinyamahumba, Zurura, Nyamidzi, Denzva, Nyahangare, Chiduku, and Ruombwe did not experience any major fire outbreaks in 2005. In 2006, 341 incidents were detected, as compared to 743 incidents that were detected in 2005. There is a 54.01% disparity from last year's outbreaks. A total of 330 incidents were detected in farms, while the remaining 11 incidents were detected in Rongwe, Dowa, and Ngome, as shown in the Table 2.

Table 1: Number of Fire Incidents Detected per ward

WARD	**NUMBER OF INCIDENTS DETECTED**
Batanai	4
Chitangazura	6
Dowa	15
Dumbamwe	3
Gweza	4
Matotwe	2
Nyamagura	1
Ngome	3
Rongwe	4
Tsagura	8
Surrounding Farms	696
TOTAL	**743**

Table 2: Fire incidents per ward for Makoni District 2006

WARD	NUMBER OF FIRE INCIDENTS
Dowa	9
Ngome	1
Rongwe	1
Farms	330
TOTAL	**341**

Dowa ward had the highest fire incidents that were detected in communal areas. It recorded a total of 9 detections of major fires, followed by Ngome and Rongwe, which had 1 each. The communal areas accounted for 3.23% of the total incidents detected, Dowa alone had 2.64%, and the farms had the most prevalent detected incidents, constituting 96.77% of the total detected incidents. In 2005, the Chimanimani District recorded a total of 693 fire incidents throughout the district within the months of September and October, recording the highest number of incidents with a total of 221 incidents, respectively. In 2006, the Chimanimani district recorded a 78.5% drop in fire incidents from a total of 693 in 2005 to a total of 149 in 2006. September and October accounted for the highest fire outbreaks of 32% followed by October with a total 25%, July of 6%, January and June contributed 2% each and February contributed 1% (Table 3).

Table 3: Monthly Spatial Distribution for Chimanimani and Makoni Districts for 2005- 2006

CHIMANIMANI 2005			**CHIMANIMANI 2006**			**MAKONI 2005**			**MAKONI 2006**		
Month	Fire Incidents	% of Total Incidents	Month	Fire Inciden ts	% of Total Incidents	Month	Fire Incidents	% of Total Incidents	Month	Fire Incidents	% of Total Incidents
Jan	14	2.02	Jan	0	0	Jan	1	0.13	Jan	0	0
Feb	5	0.72	Feb	0	0	Feb	0	0	Feb	0	0
Mar	1	0.14	Mar	0	0	Mar	0	0	Mar	0	0
Apr	1	0.14	Apr	0	0	Apr	6	0.81	Apr	0	0
May	0	0	May	0	0	May	8	1.08	May	2	0.59
Jun	17	2.45	Jun	0	0	Jun	43	5.79	Jun	2	0.59
Jul	41	5.92	Jul	20	13.42	Jul	131	17.63	Jul	38	11.14
Aug	221	31.89	Aug	41	27.52	Aug	290	39.03	Aug	106	31.09
Sep	221	31.89	Sep	46	30.87	Sep	140	18.84	Sep	165	48.39
Oct	172	24.82	Oct	42	28.10	Oct	124	16.69	Oct	28	8.20
Nov	0	0	Nov	0	0	Nov	0	0	Nov	0	0
Dec	0	0	Dec	0	0	Dec	0	0	Dec	0	0
TOTAL	**693**	**99.99**		**149**	**99.91**		**743**	**100**		**341**	**100**

In 2005, fires started as early as January where there were 14 outbreaks, which were all detected in Charter Forest Plantation, as shown in Figure 5. May, November, and December recorded nil fire incidents, while the highest outbreaks were detected in August and September, where a total of 221 incidents were detected apiece. March and April had one outbreak detected in each. In August and September, the majority of the fires erupted in the exotic tree plantations of Charter, Gwindingwi, Martin, and Tilbury Forests.

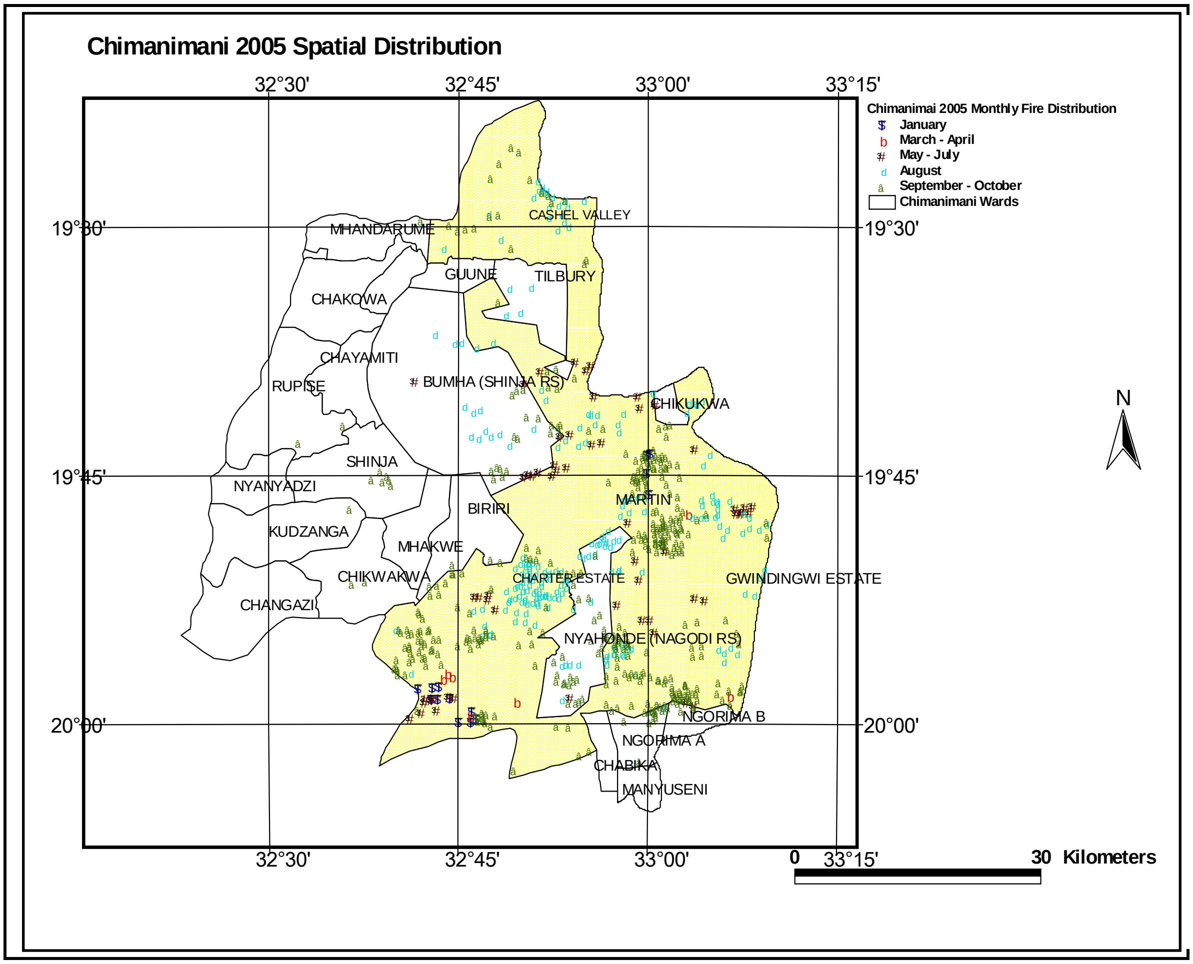

Fig 5 Monthly spatial distribution by location for Chimanimani 2005.

In August there were 221 fires detected throughout the district, while September and October had a total of 393 fire outbreaks. November and December, however, did not experience any major outbreaks.

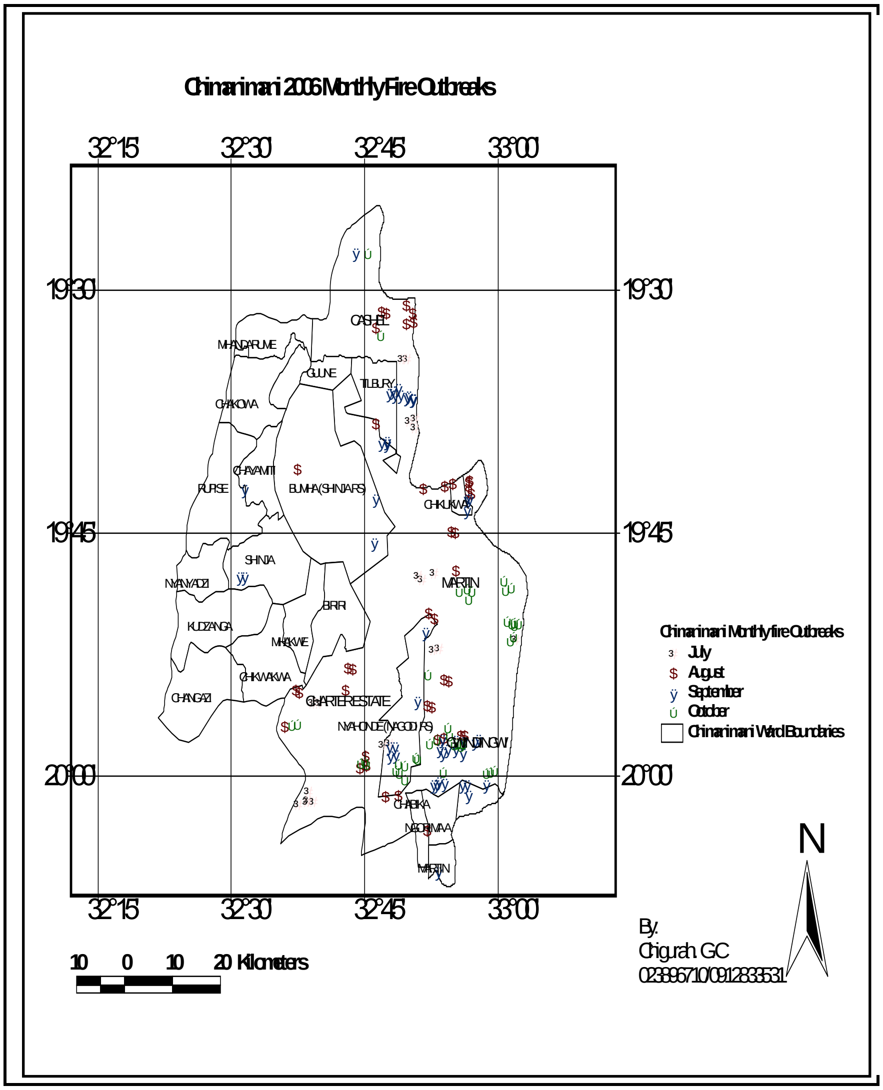

Fig 6: Monthly fire incidents for Chimanimani Districts by location in 2006.

In 2006, the fire season started late with the first outbreaks of major fires detected in July, where 20 outbreaks were detected. In 2006, major outbreaks were only detected in July, which had 20 outbreaks, August, which had 41 outbreaks, September, which had 46 outbreaks, and October, which had 42 outbreaks, with the highest outbreaks occurring in September, where 46 incidents were detected. There were no major fire outbreaks from January – June and from November – December, as shown in Figure 6.

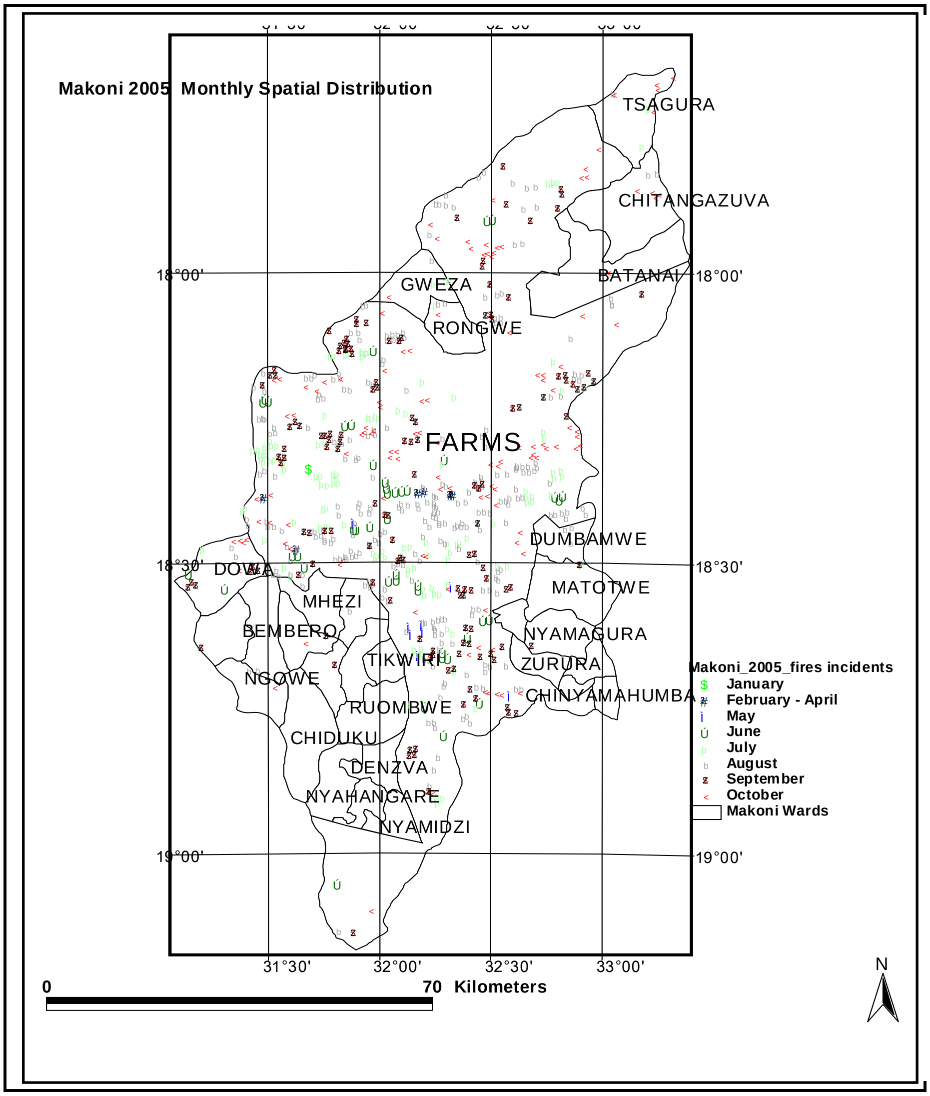

Fig 7: Makoni monthly spatial distribution for 2005.

Makoni district recorded the highest number of wild fire outbreaks in 2005, with a total of 743 outbreaks being detected, with the highest of 290 recorded in August. The fire season in the Makoni district in 2005 started earlier than in 2006. In 2005, the veldfire season started in January, although no incidents were recorded between February and March. Only 1 incident was recorded in January, 6 in April, 8 in May, 43 in June, 131 in July, 290 in August, 140 in September, and 124 in October, as illustrated in Figure 7. The month of August, in 2005, accounted for 38% of the total fire incidents detected in the whole district. August had the highest detections of fire incidents, followed by September, which had 19%, July with 18%, October with 17%, June 6%, and April and May, with 1% each. February, March, November, and December did not experience any major detectable fire outbreaks, hence they all recorded a nil percentage. The lowest outbreaks erupted in April and May, which shared 1% each.

In 2006, there was a remarkable improvement in fire outbreaks for Makoni district. The total number of outbreaks dropped from 743 outbreaks in 2005 to 341 outbreaks in 2006 due to the late start of the fire season in 2006.

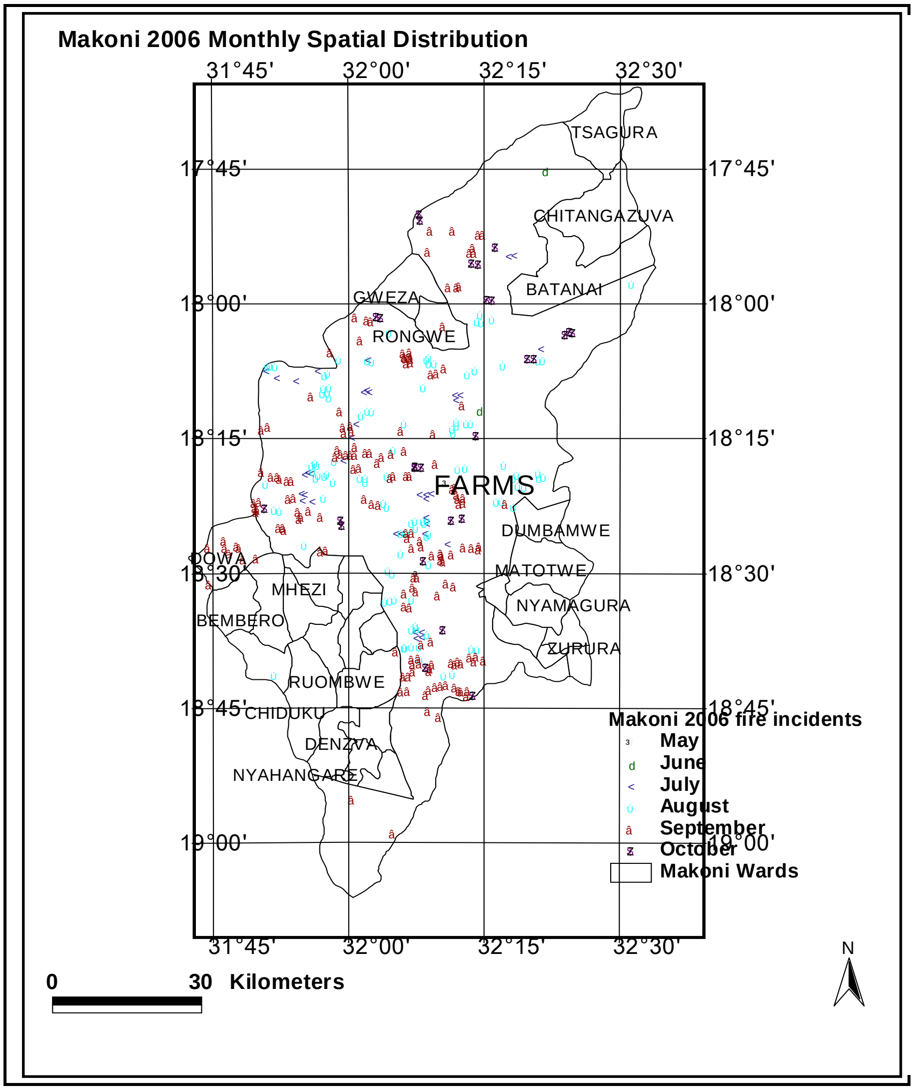

Fig 8: Monthly spatial distribution for Makoni 2006.

The year 2006 registered a 54.10% drop in fire outbreaks from 2005. As is indicated in Figure 8, no fire outbreaks were recorded from January to April of 2006 in Makoni. This contributed to a drop in fire incidents for 2006. The highest detection was recorded in September with a high of 165 outbreaks. July, August, and October recorded a total of 38, 106, and 28 fire outbreaks, respectively. May and June recorded a maximum of 2 outbreaks, each.

The month of September recorded 48% (almost half) of the total fire incidents that erupted in the district. These were all detected in the farms, except for one incident that was detected in Rongwe district. August had the second highest percentage, of 31%, of the total incidents, followed by September, which had 11%, October, with 8%, and finally May and June, with 1%, each.

The relationship between fire incidences and Crop use/Crop Use Intensity (CUI) and vegetation cover and type

Agriculture is the major economic activity in Chimanimani and Makoni Districts. It is practiced using different techniques which include dry-land farming, irrigated agriculture, livestock farming, and horticulture. These types of farming are also determined by the agro-ecological regions (I - V) and the land type in which they fall under. The Eastern part of Chimanimani district, which lies in agro-ecological regions I and II, is characterized by both indigenous and commercial forest plantations (Figure 9). The percentage of crop use intensity usually determines the likelihood of fire occurrences as fire illuminates and spreads rapidly where there is dense vegetation cover during the fire season.

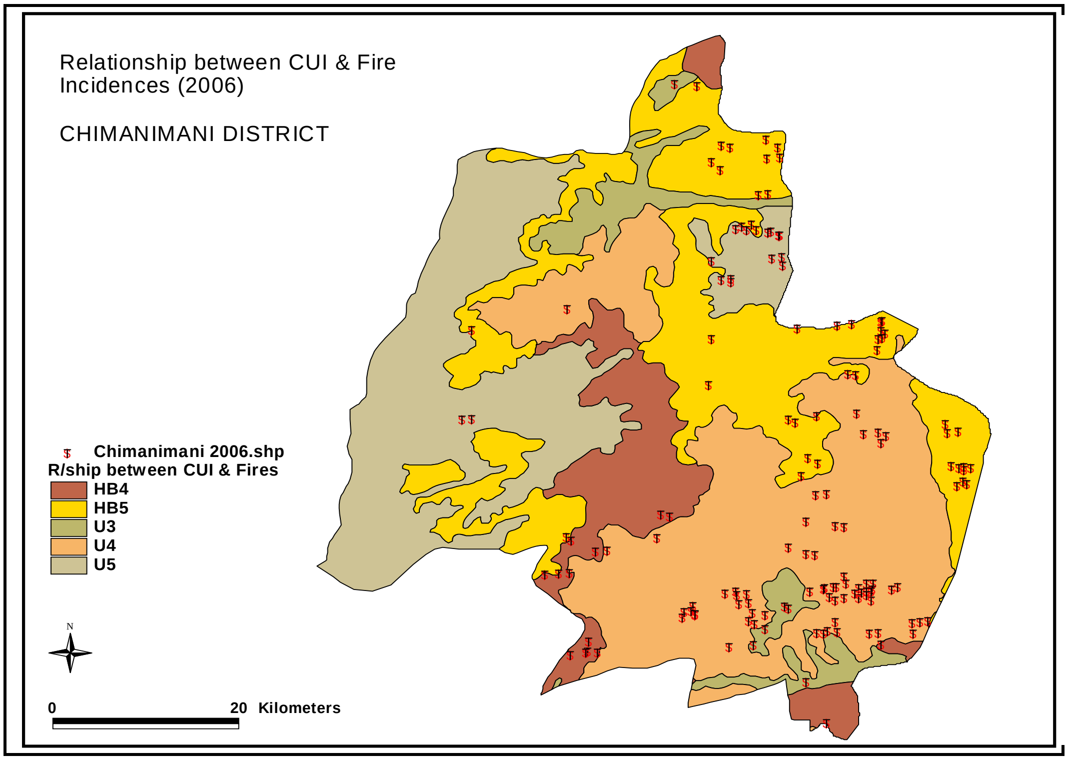

Fig 9: The relationship between CUI and Fire Incidences.

The legend on crop use intensity is explained as follows:

HB3: Hilly, broken (30-49% crop use intensity).

HB4: Hilly, broken (5-29% crop use intensity).

HB5: Hilly, broken (0-4 % crop use intensity).

DI 1: Developed, irrigated (70-100% crop use intensity).

DI 3: Developed, irrigated (30-49% crop use intensity).

U3 : Uplands (30-49% crop use intensity).

U4 : Uplands (5-29% crop use intensity).

U5 : Uplands (0-4% crop use intensity).

W : Open water.

Besides illustrating crop use intensity for specific areas, the data can also be used to describe the physical relief of an area. Most of the fires that erupted were detected in uplands (U4), where crop use intensity is between 5% and 29%. This is because the area is mostly covered by exotic forest plantations due to its terrain, which is not suitable for crop growth. The least detected fire incidents were detected in Uplands (U5), where crop use intensity is between 0% and 4%. This area occupies the western part of the district and it is comprised of communal areas, except for Tilbury Forest Plantation to the northeast, which is comprised of Pine and Wattle plantations.

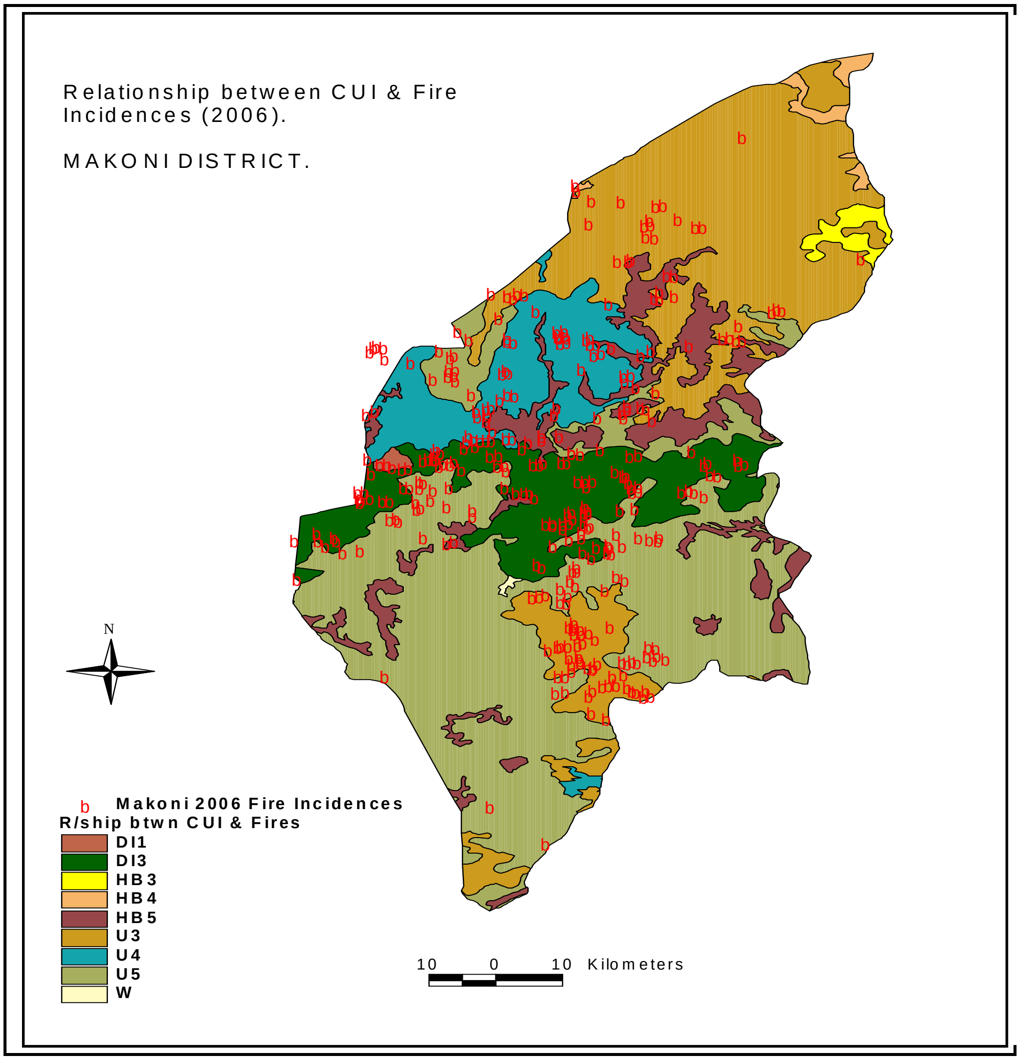

Fig 10: The relationship between CUI and Fire Incidents in Makoni District

The majority of the fires in Makoni District were detected in areas where crop use intensity was between 30% and 49% (DI 3). This area is comprised of well-developed irrigation structures that enable the growing of crops throughout the year and in uplands were crop use intensity was between 30% and 49%. The lowest fire incidents were detected in hilly-broken areas

(HB 5) where crop use intensity was between 0% and 4%, meaning that the crop production is not intensive, hence the ground cover is very low (Figure 10).

How effective was the system of detecting and reporting fires?

The years from 2006 to 2009 saw a more passive posture being taken by the Environmental Management Agency in a bid to curb the tide of destruction resulting from incidences of veldfires or bushfires. The National Fire Prevention Strategy, which was launched in Chimanimani, steered in a ‘new’ holistic fire prevention and management approach, which, in part, saw the collection of fire statistics in the province from all the seven districts by the Environmental Management Agency staff based in the districts.

Fire incident reports from the two districts were vastly inconspicuous, compared to MODIS satellite fire detectors. During the fire season, all fire incidents in both districts did not correspond with the data that was detected by MODIS. For example, in the month of September, Makoni and Chimanimani EMA district staff reported 11 and 2 fire incidents, respectively, whilst MODIS fire detector captured 165 and 46 fire incidents for both districts, respectively. The total number of incidents recorded by Chimanimani Officers for 2006 was 12 compared to 149 incidents that were detected by MODIS. For Makoni district, MODIS detected 341 incidents while officers recorded a total of 25 incidents for the whole veldfire season with a percentage difference of 92.7%. This scenario, therefore, undoubtedly promotes the use of satellite detectors in fire incidents reporting and monitoring as it confers accurate information.

Fire Incident Recurrence Interval

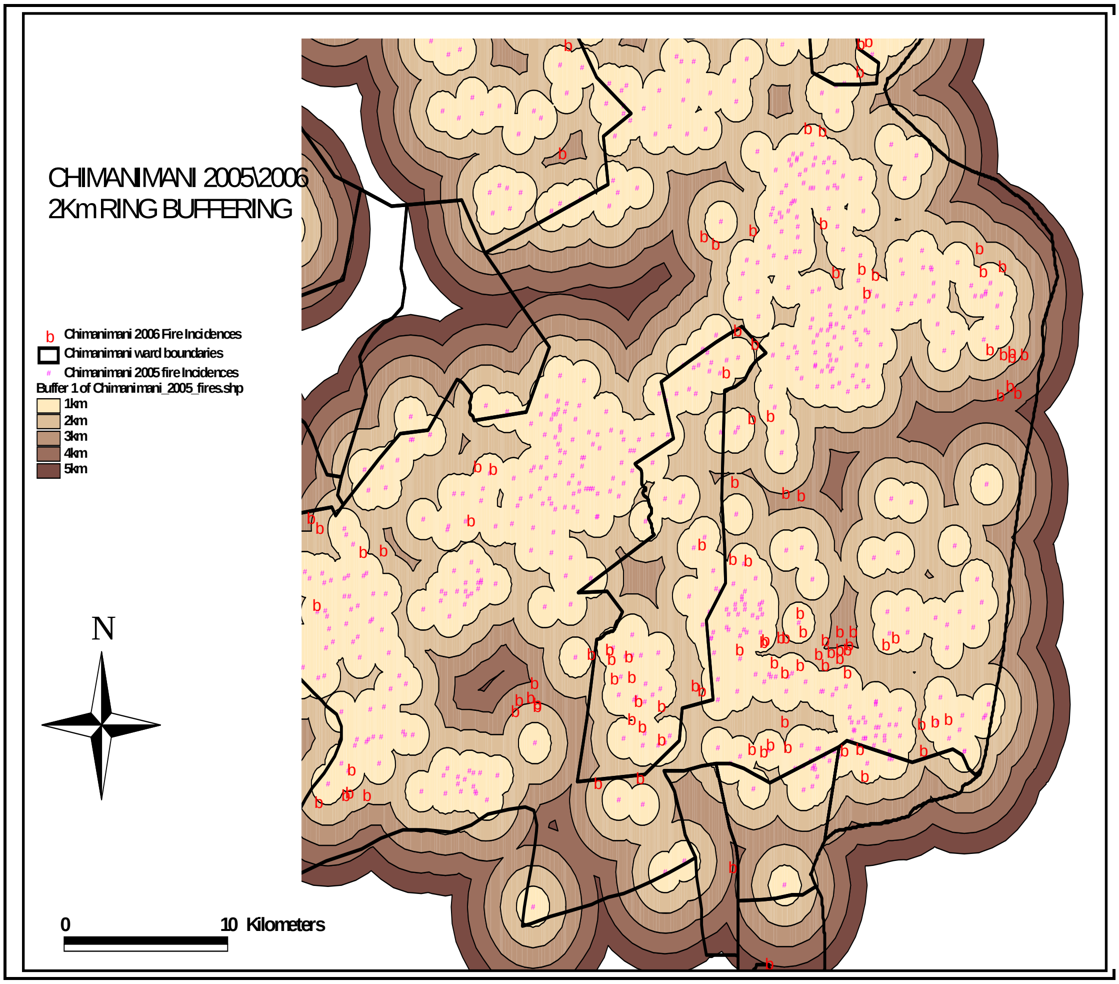

Fig 11: Chimanimani fire recurrence interval.

The location of the 2006 incidents is not very different from the 2005 fire detections. However, there was a slight change in the recurrence interval as 93.96% of the 2006 detected fire incidents were detected within the range of a 1-2 km buffer zone, particularly in the southeastern part of the district. 6.04% incidents occurred within the 3-4 km buffer zone in the northeastern part of the District, as shown in Figure 11.

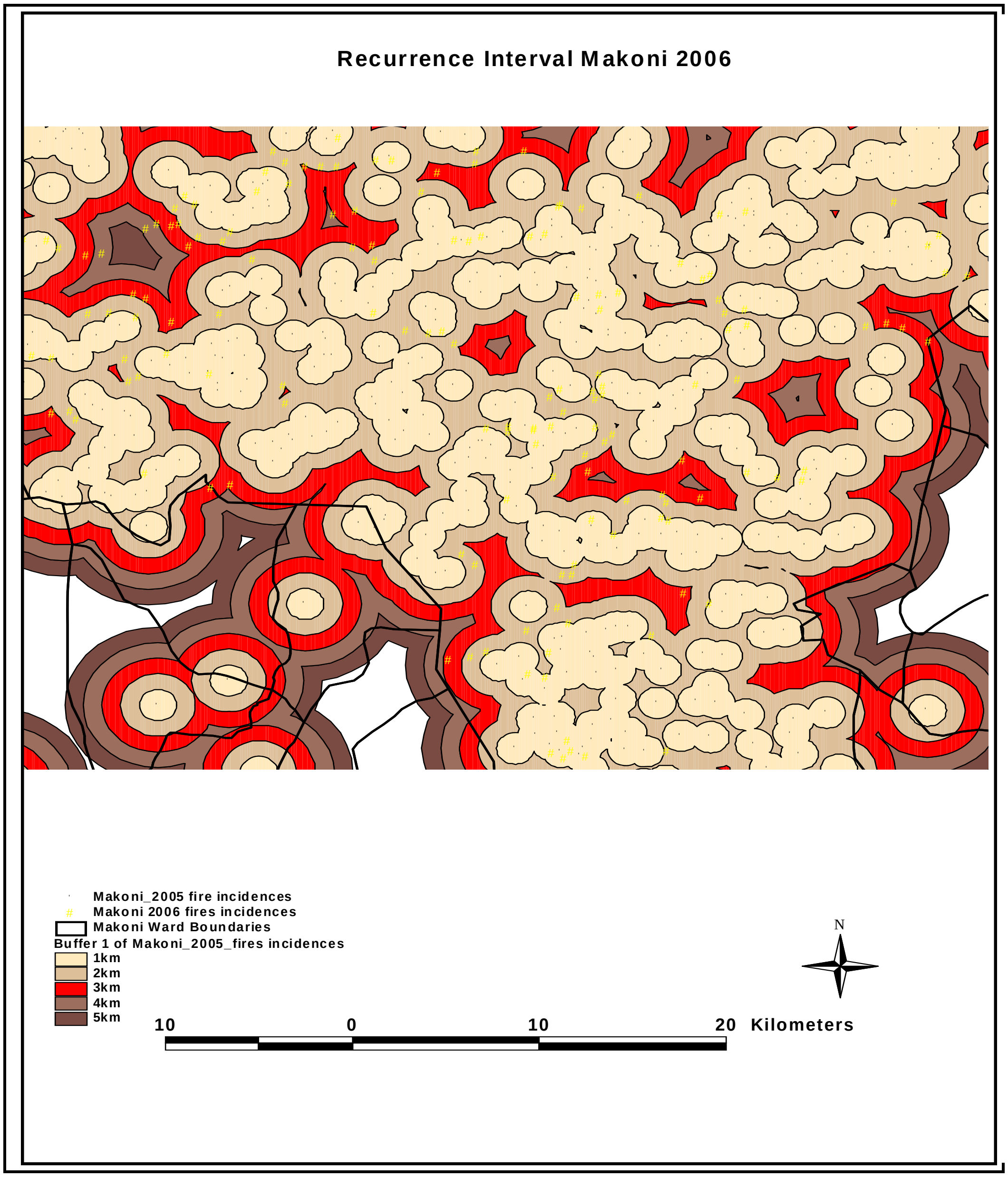

Fig 12: Makoni Recurrence Interval

The recurrence interval for Makoni district, as shown in Fig 12, is not very different from that of Chimanimani District because the majority of the detected fire incidents erupted within the 1-2 km buffer zone. The 3-4 km buffer zone, from the previous year's incident, had 9.4% of the 2006 detected fire incidents, whilst the remaining 90.6% were within the 1-2 km buffer zone from the previous year's outbreak. In Makoni, most outbreaks were recorded in resettlement farms, as indicated in Fig.12, with only a few outbreaks in the communal lands.

Background knowledge on the application of remote sensing in detection of veld-fire incidents

A total of 38% of the officers knew how to apply and integrate Remote Sensing techniques with GIS and the remaining 62% expressed ignorance on its applications. The 38% said they learned how to use the GIS software and remote sensing techniques while there were still at college. Given that the officers have the appropriate GIS software, 25% preferred to use remote sensing techniques given the vehicle and fuel crisis that was being experienced in the two districts. Remote Sensing would reduce and ease the transport and fuel costs and increase efficiency in data collection, evaluation, and monitoring. 12.5% preferred to use data from the public and ground measurements and the remaining 50% preferred to use both methods to increase the validity and accuracy of the statistics collected. Remote Sensing is very useful in detecting fires in remote areas that are inaccessible by vehicles.

DISCUSSION

Chimanimani and Makoni Districts experienced high detections of incidents in August and September of both 2005 and 2006 because, during this time, the districts would be experiencing a warm, dry season, which stretches from mid-August to November. This is a warm, dry season because Zimbabwe experiences a continental type of climate, which is divided into four seasons, namely:

The rainy season (November to mid/late March)

The post-rainy season (mid/late March to mid May)

The cool, dry season (mid May to mid August)

The warm, dry season (mid August to November).

During the warm, dry season, temperatures in the Chimanimani and Makoni districts will be averaging 18^{o}C. Maximum temperatures in August will be around 18^{o}C and in September, maximum temperatures will be around 21^{o}C. Surface fuels in the forest plantations that of the Chimanimani District raise crown fuels to ignition temperature as a result of convective heat transfer. The winter rainfall in the exotic forest plantations of the Chimanimani District and resettled farms of the Makoni District stimulates the growth of non-native annual grasses that filled interspaces between trees with continuous fine fuels. This facilitates an increase in the spread of veldfire in both districts in August and September.The topography of the majority of forest plantations in the Chimanimani District is extremely rugged, with ranges of jagged peaks and deep ravines. The main plateau is at an altitude of 1500–1800 m, with peaks reaching 2400 m and dropping to 320 m in deep gorges and river valleys. Topography influences the movement of air directing a fire’s course. Fires burn faster uphill than downhill because of the pre-heating of the uphill fuels and the influence of daytime upslope winds. This is the reason why 83.84% and 75.17% of the total fire incidents detected in 2005 and 2006, respectively, were in forest plantations of the Chimanimani District with a crop use intensity classification of (U4), meaning that they are uplands with 5-29% crop use intensity.

Communal areas experienced low fire outbreaks due to the availability of natural fireguards created by animal and human tracks, settlement patterns, and cultivation. The communal areas are fragmented by settlements, cultivation, and well-developed human and animal tracks making less fuel available for fire and preventing the spread of fires from one point to another. The communal areas are also heavily grazed by domestic and wild animals, thereby reducing the amount of fuel available for a fire.

The recurrence interval for both districts were within the 2-4 km vicinity and the overall reduction of fire incidents in 2006 were mainly a result of the vast outbreaks being experienced in the previous fire season of 2005, which consumed huge amounts of fuels thereby reducing the amount of fuels available for the 2006 veldfire season. The discrepancy in reporting of fire incidents by EMA staff was a result of:

Inaccessibility. Some areas where fire outbreaks were captured by MODIS are inaccessible to people, which makes it difficult to recognize and record such incidents.

Immobility. EMA staff could not swiftly identify fire outbreaks in all wards of the district because of immobility resulting from erratic supply of fuel and availability of motor vehicles. This made it difficult to carry regular inspections in all the wards.

Disinclination by communities to report any fire outbreak to EMA offices made it virtually impossible to keep up to date records of fire incidents in all the districts.

GENERAL FINDINGS THAT HAVE BEEN MADE

Fire Detection and Monitoring.

The use of satellites in the role of monitoring, mapping, and analyzing fire activities have been amply illustrated in recent years (Harris Flynn, Dean, Pilger, Okubo and Rothery, 2000; Flynn, Harns, Rothery and Oppenheimer, 2000; Shneider, Dean, Dehn, Miller and Kiriaov,2000; Pauss and Valego, 1999). These studies concentrate on high temporal resolution and low spatial resolution data sets that are refreshed regularly and hence are ideal for continuous monitoring of fire activities. According to Frost and Vasloo (2006) the perfect fire detection satellite, which would be capable of identifying very small fires over large areas regularly, does not exist yet.

Wooster and Rothery (2000) defined MODIS as a nadir viewing system, having a swath width of 2,330 km and offering 36 spectral bands of data at one time of 3 spatial resolutions of 250 or 500 or even 1000 m per pixel. Of these 36 spectral bands, 10 are useful for detecting thermal radiance from active fire activities. MODIS was launched into a sun-synchronous orbit as part of the Terra and Aqua platform of instruments in December 1999 and June 2000 respectively (Morissette, Priyette and Justice, 2002). The two MODIS satellites are polar orbiting and are moving around the North and South Poles every 98 minutes, while the earth is turning from west to east. Terra scans the Southern African region between 10h00-11h30, while Aqua scans in the afternoons between 14h00-15h30. Each satellite also scans the region at night (Terra at 22h00 and Aqua at 03h00). Polar orbiting satellites have the advantage of detecting small fires, but with a very low overpass frequency, while geostationary satellites have the advantage of frequent views over large areas (every 15 minutes), but with a very low resolution that can detect big fires only (Frost & Vasloo, 2006). Each fire that is detected represents the center of a 1 km pixel, flagged as containing one or more actively burning fires within that pixel. In any given scene, the minimum detectable fire size is a function of scan angle, biome, sun position, land surface temperature, cloud cover, amount of smoke, and wind direction. The precise value varies slightly with these conditions, but, generally, in many biomes the minimum flaming

(~800-1000K) fire size is typically detectable at a 50% probability with MODIS and is in the order of 100m^2. Because each fire event is fitted in a 1 km pixel, independently of its size, it makes the exact location of the fire incident difficult in the field, unless the fires are directly monitored and mapped in the field. Small hot fires late in the dry season can be detected and it has been shown in 1 km pixel, which makes searching for the exact position in a 1 km^2 grid difficult. MODIS fire information can be a very powerful fire monitor tool where ground measurements can be carried out immediately after or during the fire incidence.

Wildfire Temperature Retrieval

Wildfire temperature retrieval commonly uses measured radiance from a middle infrared channel and a thermal infrared channel to separate fire-emitted radiance from the background emitted radiance. Dennison, Roberts, Thorgusen, Regelbrugge, Weise and Lee (2003) suggested that emitted radiance at shorter wavelengths, including the shortwave infrared, is measurable for objects above a temperature of 500 k. The spectral shape and radiance of thermal emission within the shortwave infrared can be used to retrieve temperature.

Fire propagates through the combustion of fuels consisting of live and dead plant material. Fuel temperature must be high enough to volatilize and ignite these materials. Once ignition has occurred, the energy released through combustion raises the temperature of adjacent fuels. Pyne, Andrews and Laven (1996) link the stages of combustion to temperatures at which they typically occur. As fuel temperature increases above 400 k, the volatilization of fuels begins in a process called pyrolysis. As the temperature of the combusting fuels increases, the energy radiated by the fire increases and shifts to shorter wavelengths. By measuring thermal emission within multiple channels, remote sensing can be used to determine the dominant temperature and location of a fire.

Factors Determining Incidents and Effects of Veld-fires

There are many factors which determine the occurrence and effects of veld-fires such as weather patterns, socio-economic, and demographic trends and vegetation types.

Meteorology

The dominant meteorological variables influencing the development of fires are temperature, wind speed, air relative humidity, and stability of the atmosphere. In the stable and dry summer environments, the energy received from the sun increases temperature and reduces the relative air humidity. Both variables (temperature and relative humidity of the air) control the hydration state of dead fuels. The number of days with maximum extreme temperatures will increase in the summer.

The spread of fire is favored during the day by the temperature increasing and the relative air humidity decreasing, which can reduce the moisture content of dead fuels, lowering the threshold for ignition and making an ignition event more likely to lead to fire. Likewise, night-time temperature increases will be proportionally greater than the daytime ones (Easterling, Horton, Jones, Karl…Salinger 1997). In other words, temperatures during the night tend to become comparatively higher, with the consequent negative effect on fuel moistening. Assuming that the number of ignition sources and the vegetation do not vary, flammability can, therefore, be expected to be greater and the fires more frequent, and that once they have broken out, they will spread further and get bigger. The tendencies for precipitation during this century are not consistent among models, although, they all agree that the total annual precipitation will decrease, in particular in spring and summer.

Precipitation patterns determine the level of soil moisture reserves. Re-charged periods are critical with regard to providing the soil with greater stability in water content. Assuming that total precipitation does not vary, the concentration of this in winter and the consequent lack of rainy days in spring and summer will affect live and dead fuels. This, together with the temperature increase, will cause an increment in potential evapotranspiration. Rainfall during the growth period has a great influence on the abundance of herbaceous species. Rainy springs maintain more surface moisture in the soil, leading to greater development of fine herbaceous fuels, which subsequently dries out. Temperature increases may cause the development period of herbaceous species to be advanced to early spring or winter, so that, even in a scenario of reduced springtime rainfall, this vegetation may develop well, thus contributing to an element of hazard relatively early in the year. This is more relevant in the humid areas which, in time, may become more susceptible to greater summer dryness, which may also appear earlier in the year. Furthermore, less moisture availability in the surface layers of the soil will make the dead fuels in the soil dry out sooner. The lower number of rainy days will keep them dry for a longer time. In pine forests and ecosystems with well-developed litter, there will be an increase in flammability and an increase in the period of susceptibility to fire.

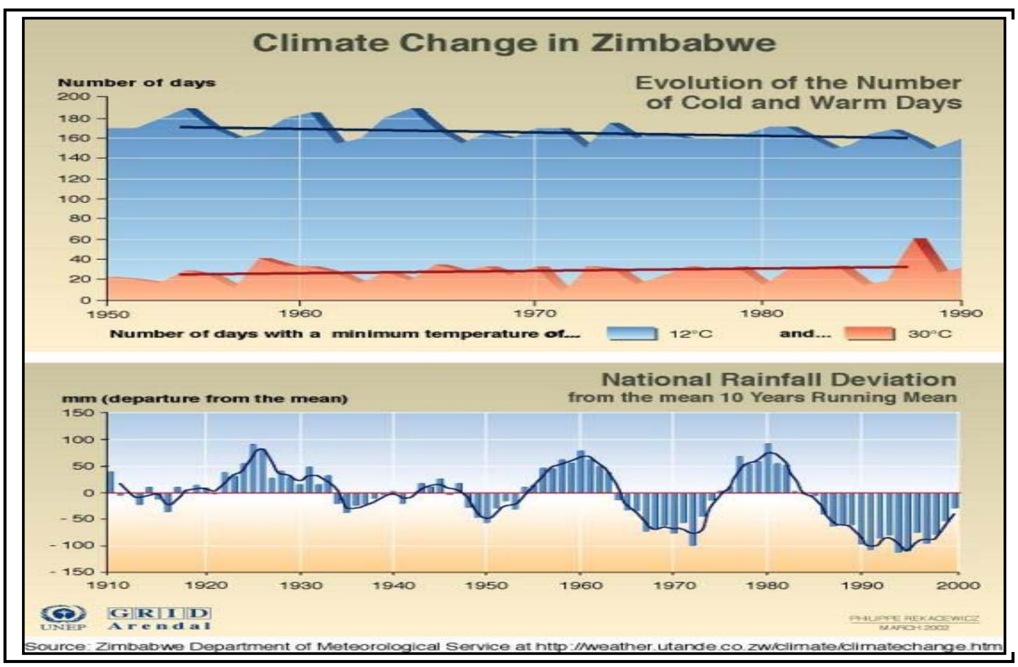

Fig 13. Climate change in Zimbabwe: trends in temperature and rainfall.

Zimbabwe is experiencing more hot days and fewer cold days, and the amount of precipitation it receives is deviating from the mean more frequently (Figure 13). This resource includes two graphics. The first shows the number of days with a minimum temperature of 12 degrees Celsius and the number of days with a minimum temperature of 30 degrees Celsius from 1950 to 1990. The second graphic shows the amount of precipitation in millimeters that was a departure from the long-term mean amount for the time period 1910 to 2000. The trends shown on both graphs favor the ignition of fires.

Wind is another critical element. The speed of the spread of the fire front is directly proportional to wind speed. The most dangerous situations are those involving strong, dry winds. *Föhn*-type winds are particularly critical. These are winds blowing on the leeward side of mountains as a result of the adiabatic compression of the air on blowing down the slopes (Millán, Estela and Badenes, 1998), and these are the cause of some of the larger fires in Spain (Gómez-Tejedor, Estela and Millan, 2000

Fire heats the air, which rises, drawing in cool air towards the base of the fire, which provides oxygen to sustainable combustion. When there is wind, this effect is augmented on the downwind side by the wind-driven airflow. The stability of the lower levels of the atmosphere determines the degree of intensity of the local wind caused by the fire. Situations of atmospheric instability favor the vertical movement of the hot air, facilitating the lateral movement of the air towards the fire front. To the contrary, in stable conditions, fires are relatively less dangerous. Thus, with two parameters of atmospheric stability, Díez, Diez, de Pablo, Sonanno (2000) calculated, to a high degree of accuracy, the daily occurrence of fires in Galicia. The synoptic situations determining the state of the atmosphere are, therefore, critical for the occurrence of forest fires (Díez, Sorrano, de Pablo, Diez 1994 These determine atmospheric flow, and, through this, wind, precipitation, or lightening discharges, among other phenomena (Gómez-Tejedor *et al*., 2000; González-Hidalgo, de Luis, Raventos, Sanchez 2001 Goodess & Jones, 2002; García-Herrera, Gallego, Hermandez, Gimeno, Ribera, Calvo, 2003; Munoz-Díaz and Rodrigo,2003; Tomás, Pablo and Soriano, 2004). Consequently, many fires occur in determined synoptic conditions (Bardají, Molina and Castrllnon, 1998). This is similar for the rest of the world (Da Camara, Lajas, Guivea and Pereira, 1998; Johnson & Wowchuk, 1993).

CONCLUSION

A total of 1 436 fire incidents were detected in Chimanimani and Makoni districts in the 2005 veldfire season, of the 1436 incidents, 159 were detected in communal areas, whilst the remaining were either detected in farms or exotic forest plantations. In 2006, there was a marked difference in the number of incidents that that were detected. The two districts recorded a total of 490 incidents with a percentage difference of 65.9%. Of the 490 incidents detected, 48 incidents were detected in communal areas. There is a huge difference between the 2005 and 2006 veldfire season due to the fact that 2005 had the highest fire outbreaks, which consumed most of the burning fuel, resulting in a decrease of fire incidents in 2006. Communal areas experienced very few outbreaks due to their settlement set up and the presence of domestic animal, which feed on dead and live grass, shrubs, and tree leaves thereby reducing the fuel capacity that cause veldfires.

The majority of the fires were detected in August and September, with both districts recording 511 and 361 incidents in August and September 2005 respectively. In 2006, there was a decrease in the same months in the occurrence of fire incidents. In 2006 there were 146 and 205 incidents for the same districts in August and September, respectively. January to June did experience less or noo utbreaks, except for Chimanimani in 2005, which experienced 14 outbreaks in January and 5 in February. Fire outbreaks are rampant during August and September because the districts will be experiencing high temperatures and no rainfall and providing suitable conditions for fire outbreaks because there will be less to no humidity in the burning fuels, which will increase the risk of ignition. Few incidents were detected in January to May because of the wetness that will be experienced during the rainy season and the low temperatures, which do not favor fire outbreaks. However, if rains are good, this will increase the amount of fuels that can burn during the dry season.

In Chimanimani in 2006, MODIS detected 149 outbreaks while the district officers reported only 12 incidents. The same applies for Makoni District where MODIS detected 341 incidents and district officers recorded 25 outbreaks in the same year. The discrepancy in officers' reporting was due to the unavailability of transport to carry out their routine environmental inspections and inaccessibility of some areas both by foot and vehicle, and disinclination by communities to report fire outbreaks to the nearest district offices.

All the eight officers in the two districts filled the questionnaires and four of them preferred using remote sensing together with ground measurements and public domain information when collecting statistics on veld-fire occurrences and natural resources management. A quarter of the officers preferred to use remote sensing and another 12.5% preferred to use public domain information and ground measurements. The 50% that preferred to use both methods appreciated the benefits of remote sensing in terms of less financial expenses and high efficiency when compiling veld-fire statistics.

RECOMMENDATIONS

A number of recommendations can be made from the findings of this study. The research demonstrates the potential use of and superiority of Geographical Information Systems and Remote Sensing data in combination with public domain data in veld management in view of the discrepancy of collected veld-fire statistics and the current resource constraints being faced by the Environmental Management Agency. In view of this, it is therefore imperative to develop a framework for the integration of Geographical Information Systems, Remote Sensing, and Public Domain data in veld-fire assessment. Therefore, there is need to utilize earth observation systems and Geographical Information Systems combined with data from districts and the public domain data to spatially investigate, understand, and map the fire occurrence and recurrence interval, awareness of fire likelihood, impact of veld-fires on vegetation, and identify focal areas in the years to come.

There is need for increase in awareness campaigns, both in communal and urban areas, with emphasis in areas near plantations, conservatives, and resettlement areas. The campaigns should cater for all individuals, including the disabled, such as the deaf, blind, and mentally unstable. Early burning should be done between May and July when maximum temperatures are at their lowest. Each district must be allocated at least one vehicle and a motorcycle to increase mobility. Districts should be equipped with computers connected to the internet and appropriate GIS software to perform spatial analysis on the data collected concerning the environmental management. Relations between district officers and the community must be enhanced to allow exchange of veld-fire information. Refresher courses must be open to everyone, regardless of their position and their station. This will assist in capacitating employees at all levels making it easier to perform regular duties.

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