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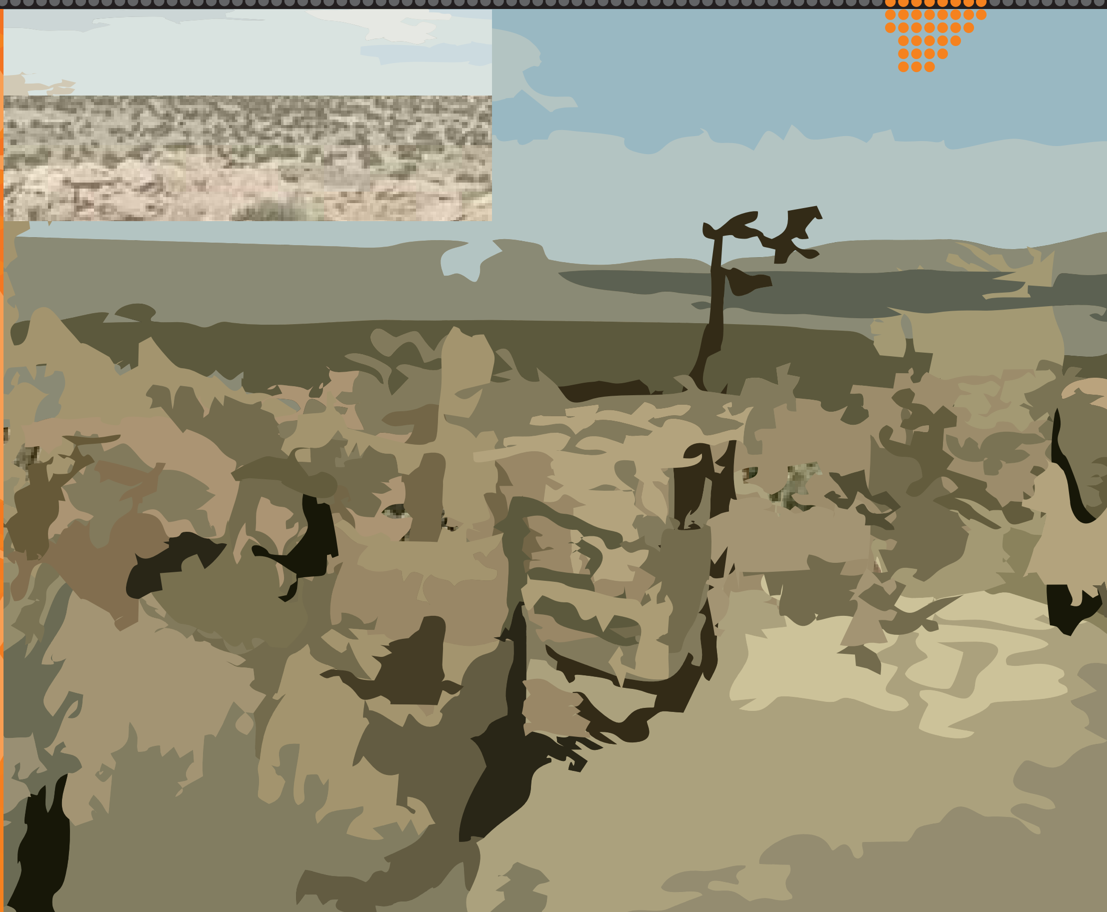

Multi-temporal threshold algorithm in forest fire detection using MSG satellite: The case of Zimbabwe

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Abstract

Forest fires have the potential to increase the amount of carbon in the atmosphere which is one of the greenhouse gases responsible for global warming. Climate change may also lead to increased outbreak of forest fires due to increased dryness conditions especially in tropical Africa. This indicates the need for improved methods for detection, monitoring and management of forest fires so as to protect the fragile ecosystems. Remote sensing has been widely used in active forest fire detection; however there are some limitations in operational contextual algorithms as they are greatly affected by clouds and different land cover types such as land and water with inherent temperatures that may be included in the 3 x 3 kernel or matrix used in estimating the possibility of fire in the centre pixel. Therefore this working paper evaluates the accuracy of the multi-temporal threshold algorithm in Zimbabwe based on the hypothesis that both multi-temporal threshold algorithm and contextual algorithm (MSG fire product) have equal performance on forest fire detection. Unlike contextual algorithms, the multi-temporal threshold algorithm estimates the mean background temperature of a point (pixel) over a number of days and any temperatures above the mean are attributed to fire. The error matrix and McNemar's test were used for accuracy assessment and testing the hypothesis of this study respectively. The preliminary results of this study have shown that the multi-temporal threshold algorithm has a higher forest fire detection rate (50.5%) as compared to MSG fire product (24.1%) which uses the contextual algorithm. There is a significant difference in the performance of these algorithms (McNemar's test statistic (x^2) = 4.7, df=1, p-value=0.0295). However this is still at a preliminary stage and further validation will be performed using 2010 and 2011 data to support and give value to these results as the multi-temporal threshold algorithm is expected to perform better than contextual algorithm. This may give more confidence to the potential users and any stakeholders interested in adopting the multi-temporal threshold algorithm in their forest fire management systems in Zimbabwe and around the globe.

1. Introduction

1.1 Background

In most African ecosystems fire is regarded as a natural and beneficial occurrence to the vegetation structure and composition, and in nutrient recycling and distribution. Fire helps in maintaining natural habitats, controlling invasive plants or species, seed dispersal thereby plays an important role in the structure and functioning of the African ecosystems. However substantial unwarranted and uncontrolled burning does occur across Africa. About 17% of sub-equatorial Africa is burned every year. This accounts for 37% of the dry matter burned globally (Scholes et al., 1996). However, there is limited capacity for forest fire monitoring and management in Africa (Dube, 2005). Southern African Development Community (SADC) (1996) noted that about 70% of the estimated 140 million people live in rural areas and directly depend on natural resources and the prevalence of forest fires hinder sustainable development as it affects the forest resources as well as agricultural systems. Therefore there is need for effective actions to protect life, property, and fire-sensitive natural resources, and to reduce the current burden of emissions to the atmosphere with subsequent adverse effects on the global climate system and human health (IFFN, 2004). This can be difficult to achieve without the effective and efficient operational system for near real time active fire detection and monitoring in this region. The most important part in the process of understanding the effects of fire on the atmosphere is to have accurate and reliable information on time and location of forest fires through the application of remote sensing (Morisette et al., 2005).

The significance of forest fires in Sub-Sahara Africa, particularly in the SADC region, in shaping fire adapted and highly productive ecosystems versus its destructive role of excessive fire threatening the sustainability of natural and land-use systems, requires human resources and capacities enabled to deal with the complexity of the issue. Spatio-temporal awareness of fire likelihood, occurrence and behavior is key to appropriate prevention, response and management (McFerren, et al., (2009). There are many research and development organizations working on fire prevention, reduction and management in Southern Africa including International Southern African Regional Science Initiative (SAFARI) - 2000, Regional Sub-Saharan Wildland Fire Network (Afrifirenet) and the Southern African Fire Network (SAFNET). Afrifirenet developed the South African Advanced Fire Information System (AFIS) which is one of the first near real time satellite based fire monitoring system in Africa (Frost and Scholes, 2007) which uses MODIS and MSG satellite fire products. The Fire Information for Resource Management System (FIRMS) developed at the University of Maryland (USA) is also providing MODIS active fire data to natural resource managers, scientists and policy managers in 58 countries and these include countries in Southern Africa (Groot et al., 2007). The Environmental Management Agency (EMA) in Zimbabwe is also applying the MODIS and MSG fire products. However, the contextual algorithms applied in these systems are subject to errors and proved to be less accurate as compared to multi-temporal threshold algorithms (Kaufman et al., 1998; San-Miguel-Ayanz et al., 2005; Hassini et al., 2009; EUMETSAT 2007; Manyangadze 2011). However there is need for further rigorous development and validation of this multi-temporal threshold algorithm.

In Zimbabwe forest fires are a critical issue as they account for great environmental degradation such as soil erosion and deforestation. About 800 000ha of land cover were destroyed by forest fires in 2006, while 33 804ha were burned in 2007 (Zvinonzwa, 2008) which indicate a threat to biodiversity including vegetation and wild animals. A multi-sectoral approach should be adopted in order to curb or at least reduce the incidences of these widespread ecological disturbances. These fires mainly occur in the fire season (dry season) between May and October every year. Therefore this project is set out to validate the multi-temporal algorithm developed by Manyangadze (2011) as a step towards improving the satellite forest fire monitoring system in Zimbabwe. The multi-temporal threshold algorithm was developed using the 2005 and 2007 ground data from Portugal and applied once over Southern Africa (2007 data) for comparison with MSG fire product with MODIS as reference data (Manyangadze, 2011). This indicates the need for more validation in different setting from Portugal to support the results from the first study.

1.2 Problem statement

Generally, rural Zimbabwe is affected by wild fires during the dry season (WWF, 2001). Fire negatively affects the fragile ecosystems and the socio-economic systems of many developing countries especially in Africa including Zimbabwe. According to the Ministry of Environment Resources Management (MENRM) property worth Z$1, 245 trillion was lost due to fires in 2005 and Z$328 billion in 2004 which is three fold increased in property lost, and the fires claimed seven lives in 2005. Therefore there is need for early detection of these active fires to reduce the damages. Groot et al., (2007) noted that there are efforts in developing satellite systems for early and accurate detection. In this regard the multi-temporal-threshold algorithm proved to be superior over MSG fire product when applied in Portugal (50% compared to 3.7%) and the whole of Southern Africa (75% against 12.1%) (Manyangadze, 2011). Although the method was compared to MSG fire product with MODIS fire product as a reference data over Southern Africa, there is still the need to validate this method in a near real time manner so as to confirm its effectiveness and efficiency as compared to MSG fire product.

This study has a potential to contribute significantly to responsible innovations for African Development. This algorithm will be developed into a forest fire product alongside MODIS and MSG fire products and augment the efforts by different stakeholders such as Environmental Management Agency (EMA) and Forestry Commission in forest fire management in Zimbabwe. This study is expected to offer a platform for stakeholder participation and pulling of the resources towards the forest fire management in Zimbabwe. The solo fighting of this problem by individual organizations such as EMA, Rural District Councils, and Forestry Commission may prove expensive and fruitless. The ability to minimize the destructive impact of fires is directly related to how early we can identify and respond to them. A quick and effective reaction to forest fires will increase the chances of putting fire out and reducing the damage to the environment (WWF, 2001). This is particularly true for forest fires that spark up in the poorly monitored parts of the country. The study also aims to confirm the capability of the multi-temporal algorithms to detect more forest fires compared to contextual algorithms.

1.3 Study area

Zimbabwe is located in Southern Africa, mainly characterized by three major climatic regions: wet (highveld), semi-arid (middleveld) and arid (lowveld) regions. Rainfall distribution in these regions, determines the prevalence or occurrence of fires. In wet regions with rainfall above 1000 – 1200mm/yr, there are closed plant canopies and prolonged moist conditions which limit the spread of fires (Roy et al., 2005). The semi-arid region is mostly affected by fires as they are characterized by woodland savanna with average rainfall of about 550 – 750mm/yr as well as hot, dry and windy conditions which increase the risk of forest fires (Trollope et al., 2004). The arid region (west and southwest interior) receive rainfall of less than 550mm/yr and the vegetation is mainly shrubs and grass production is determined by the annual rainfall therefore fires are normally intermittent and normally follow the periods of well above average rainfall (Roy et al., 2005). This study covers the whole of Zimbabwe and further studies on the performance of this algorithm in different regions of Zimbabwe will be carried out at a later stage.

1.4 Research Objectives

The main objective of this study is to assess the accuracy of the multi-temporal threshold algorithm in forest fire detection and monitoring compared to MSG fire product in Zimbabwe using both MODIS and ground data as reference datasets.

The specific objectives are:

- To assess the accuracy of the multi-temporal threshold algorithm
- To compare the accuracy of the multi-temporal threshold algorithm and MSG FIR-G fire product.
- To come up with recommendations on how remote sensing technology can be integrated into the current forest fire policy and management systems in Zimbabwe.

The study hypothesized that there is no difference in forest fire detection rate between the multi-temporal threshold algorithm and MSG fire product. This hypothesis is tested in Zimbabwe using different datasets for 2007, 2009, 2010 and 2011 to provide conclusions as to whether it could be implemented or supported, and to give recommendations based on those conclusions.

2. Literature Review

2.1 Forest fires and climate change

African ecosystems have a great role in terrestrial carbon cycle by acting as carbon sink; however African continent is responsible for 37% of the carbon emissions (Williams et al., 2007). This is mainly due to savannah fires attributed to human land-management systems (Lehsten et al., 2008). These fires contribute significantly to the total carbon emissions such as carbon Dioxide (CO2), Carbon Monoxide (CO), and, Volatile Organic Compounds, Black Carbon over large parts of the continent. In Southern Africa, about 168 million hectares burn annually, nearly 17% of a total land base of 1014 million hectares, accounting for 37% of the dry matter burned globally (IFFN, 2004). The significance of forest fires in Sub-Sahara Africa, particularly in the SADC region, in shaping fire adapted and highly productive ecosystems is controversial due to its contribution to climate change thus threatening the sustainability of natural and land-use systems (IFFN, 2004). This shows the need for more vigorous and robust forest fire detection and response systems to reduce the effect of forest fires on climate change as well as natural and land-use systems. Hence the validation of the multi-temporal threshold algorithm so it can be improved and applied in operational systems in forest fire detection in Zimbabwe and possibly adopted in other countries as well.

Zimbabwe has extensive vegetation cover which is a net sink of carbon; however the increase in urbanization, population and energy demand are likely to increase the CO2 emissions by 250% by 2030 (APINA, 2009). It is estimated that savanna burning and emissions from agriculture related activities including veldt fires in Zimbabwe include: Nitorgen Oxides (NOx) 220 kt/yr; Carbon Monoxide (CO) 3000 kt/yr and fine particles (PM2.5) 240kt/yr (APINA, 2009). The increase in these levels may lead to more adverse impacts of climate change. Generally, there is a cyclical relationship between forest fires and climate as the increase in forest fires may lead to more or severe impacts of climate change and variability due to increase in green house gases in the atmosphere while climate change may lead to more dry conditions that may lead to more incidences of forest fires. In support of this argument Dube (2005) highlighted that the initial climate change assessments point to a high probability of increased frequency of hot fires in the future due to climate change in the region. These wild fires can cause a severe reduction in wildlife habitat thereby negatively affecting wildlife-based activities such as tourism and trophy hunting. This increase in incidences of forest fires requires efficient and effective system for detection and appropriate response so as to reduce the negative effects. For quite a long time Zimbabwe and the whole of Southern Africa have been experiencing an increased frequency of droughts and the challenge is to develop adaptation strategies that can mitigate the diverse and likely complex impacts of climate change at regional and national level (APINA, 2009). This highlight the need for well validated methods to provide accurate data on the occurrence of forest fires.

2.2 Forest fires adaptive and management strategies

There are efforts in management of forest fires in Zimbabwe and the whole of Southern Africa. In general, fire control systems found in the region are resource-constrained and fragmented (Dube, 2005). A lot of money has gone into fire prevention in some parts of Zimbabwe to acquire equipment such as radio networks, vehicles, control towers and the development of firebreaks (WWF, 2001). However, this effort has not significantly reduced the incidence and severity of forest fire during dry season in Zimbabwe mainly from end of July to October each year. Once a late dry season fire is burning, it is very difficult, if not impossible, to put it out. For Rural District Councils and wildlife producer communities, buying equipment is not a cost effective fire management strategy. This is why low cost solutions such as early detection together with community awareness, education and co-operation are now preferred. This study is providing the low cost early detection system that can be easily adopted by stakeholders such as Environmental Management Agency (EMA) and Forestry Commission in Zimbabwe.

The most important part in forest fire management is to have accurate and reliable information on the time and location of forest fires (Morisette et al., 2005), hence need for accuracy assessment of the multi-temporal threshold algorithm. This will also help to quantify and qualify the relationship between climate change and forest fires which could be difficult to achieve without the effective and efficient operational system for near real time active fire detection and monitoring in Zimbabwe.

Most of the current operational satellite forest fire detection systems are using contextual algorithms. These algorithms consider the background intensity in an attempt to predict the temperature of a pixel by calculating the average intensity by considering the neighboring pixels (Koltunov and Ustin, 2007). However, there are several problems associated with these algorithms such as undetected clouds, sub-pixel clouds, fire under thin cirrus clouds, mixed land and water scenes, inhomogeneous land surfaces, unknown land surface emissivity in IR3.9 channel and dusk and dawn with rapidly changing 3.9 channel values (Hassini et al., 2009; EUMETSAT, 2007). It has also been noted that even the version 4 of MODIS fire detection algorithm has a few blatant false alarms and its performance is yet to be assessed in different conditions (Giglio et al., 2003). Hawbaker et al., (2008) performed the accuracy assessment of the MODIS active fire products in the United States and they obtained 82% fire detection rate. This indicates that more can be done to improve the methods to increase the fire detection rates for near-real time monitoring. Calle et al., (2004) acknowledged that in general the contextual procedure is reliable and a large number of errors is mainly attributed to the final statistical parameters. Although this may not be a general consensus amongst the researchers, to some extent it is very difficult to set statistical parameters such as mean and standard deviation to the exact levels that they detect the fires totally free of false fire alarms and also without missing very small fires.

A few multi-temporal algorithms have been developed in a way to counteract the limitations of the contextual algorithms highlighted above (Koltunov and Ustin, 2007; Mazzeo et al., 2007; Van den Bergh and Frost, 2005; Manyangadze, 2011). These methods consider the physical properties of the target and observational and environmental factors such as land cover, time of pass, and viewing angle as conditions which determine the thermal signal measured by the satellite. This means that any changing event is regarded as anomalous if it produces a significant deviation from the natural normal behavior of the signal measured under normal undisturbed conditions (Mazzeo et al., 2007). Koltunov and Ustin, (2007) acknowledged that their method (non linear Dynamic Detection Model (DDM)) did not perform very well in forest fire detection. Udahemuka et al., 2008 highlighted the limitations of using the Diurnal Cycle Model (DCM) developed by Van den Bergh and Frost, (2005) in fire detection as some of the anomalies maybe due to partial or full cloud cover over a pixel, solar reflection, precipitation and land cover and wind fluctuations. Van den Bergh and Frost, (2005) claimed that the algorithm performed better than the contextual and threshold algorithms on MSG although it cannot perform at the same level with the MODIS fire product at the present moment. Therefore there is more to be done so as to improve early detection of forest fires so as to reduce their effects on climate change, national economy and destruction of fragile ecosystems.

3. Methodology

This section describes the data required, the multi-temporal threshold algorithm method and the validation plan as well as project plan for the implementation.

3.1 Data used

The success of this study is based on the availability of satellite data especially from MSG and MODIS. Several collaborations or links have been developed to obtain the data required to achieve the objectives of this project. MSG SEVIRI satellite data (including the images, MPEF cloud mask (CLM) and MSG - fire product) is required in running the algorithm. The MSG images were obtained from the Faculty of Geo-Information Science and Earth Observation (ITC) and EMA, and MSG products (MPEF cloud mask (CLM) and FIR-G) were obtained from EUMETSAT. The MODIS fire product for validation was obtained from NASA web database as well as from AMSED and CSIR. The MSG fire product (FIR-G) was used for comparison with the algorithm developed in this study with reference to MODIS fire product, SPOT burned area product (from VITO) and ground fire data in Zimbabwe. The MSG fire product (FIR-G) was chosen as it is also based on MSG so there are no problems with spatial and temporal resolution.

3.2 Methods

The multi-temporal threshold algorithm

The multi-temporal threshold algorithm is based on temperatures in IR3.9 channel and the difference in IR3.9 and IR10.8 channels over a period of 10 days as described by Manyangadze (2011). Thresholds for actual fire and probable fire are as shown below:

$$dT_{3.9\mu m} > m_{t(3.9\mu m)} + f_3(S_{t(3.9\mu m)})$$

$$T_{dif} > m_{dif} + f_2\,(S_{dif}) \qquad \text{(i) Actual fire}$$

$$dT_{3.9\mu m} > m_{t(3.9\mu m)} + f_3(S_{t(3.9\mu m)}) < m_{t(3.9\mu m)} + f_1(S_{t(3.9\mu m)})$$

$$T_{dif} > m_{dif} + f_4(S_{dif}) < m_{dif} + f_2(S_{dif})$$

Day time f_1= 2.5; f_2= 3; f_3=2; f_4=2.5; Night time f_1= 1; f_2=3; f_3=0; f_4=0 (ii) Probable fire

where:

$dT_{3.9\mu m(i)}$ is the temperature of the day at the same time at 3.9μm.

$S_{t(3.9\mu m)}$) is the standard deviation temperature in IR3.9 for the past anomaly free days (between 3 and 9 days).

$m_{t\,(3.9\mu m)}$ is the mean temperature in IR3.9

S_{dif} is the standard deviation of the differences in temperature for the past anomaly free days (between 3 and 9 days).

m_{dif} is the mean of the differences in temperatures in IR3.9 and IR10.8 channels for the past anomaly free days (between 3 and 9 days).

T_{dif} is the difference in temperature between IR3.9 and IR10.8 channels

Solar zenith angles are used to determine the day (<70), twilight (>70 and <90) and night (>90) conditions. The thresholds for twilight conditions are linearly interpolated. The f-values explain the deviation from the mean temperature that determines the classification of a pixel as fire, probable fire or no fire. For example if there is a large deviation from the mean there are higher chances that there is fire in that particular pixel.

Automation of the algorithm

The algorithm described in 3.2.1 above is summarized in the flow diagram (Fig 1.) below. The whole procedure is developed into an application with a series of scripts which operate in and outside Integrated Land and Water Information System (ILWIS) which is a Geographic Information System (GIS) and Remote Sensing software package, developed by ITC.

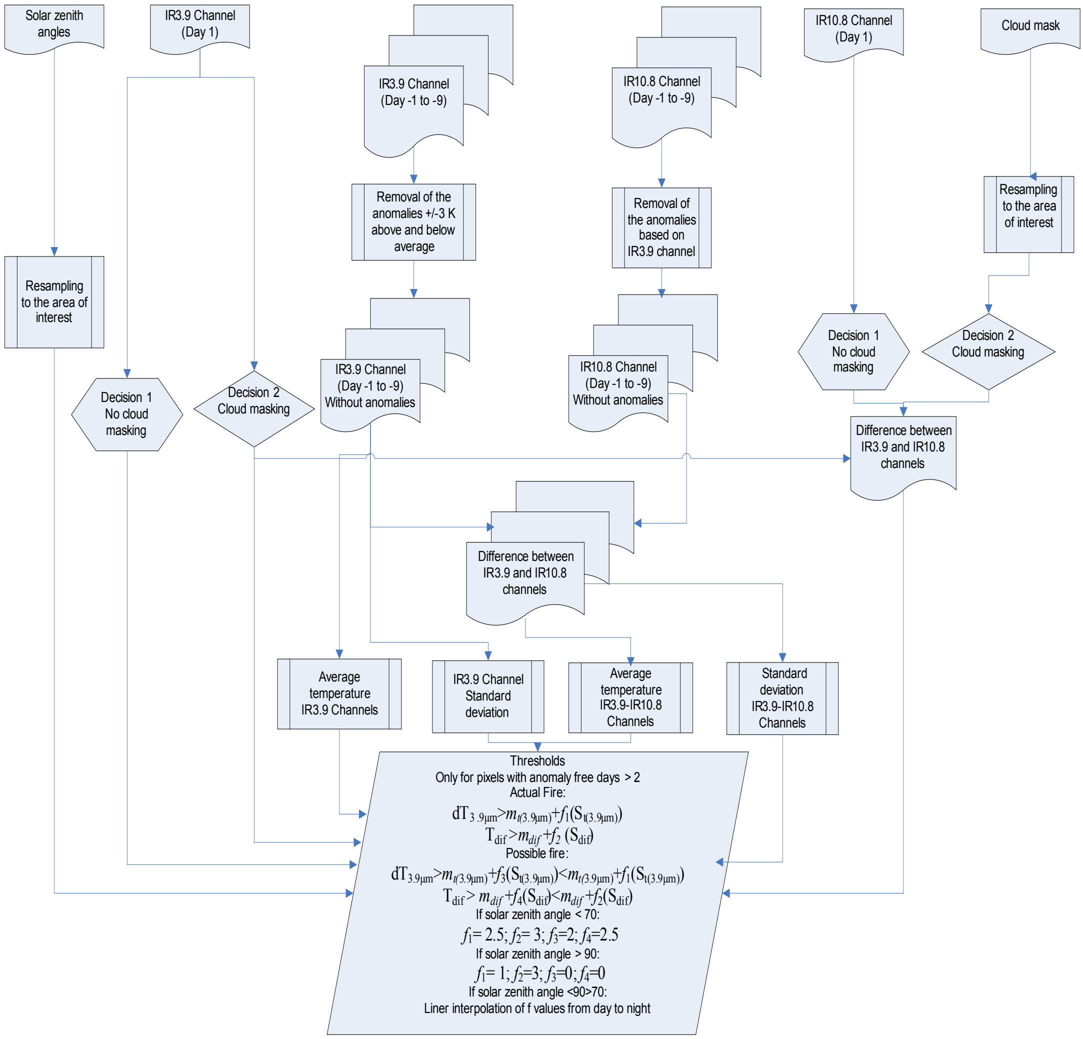

Figure 1: Automation procedure for the multi-temporal threshold algorithm (Manyangadze, 2011)

Validation

The performance of this algorithm is compared to other products mainly MSG FIR-G and the MODIS and SPOT burned area products are used as reference datasets since there is no well documented ground datasets in Zimbabwe (Hassini et al., 2009 and EUMETSAT, 2007). In the near-real time phase the verification plan has been developed and this relies on the stakeholders on the ground including Rural District Councils, Environmental Management Agency (EMA) district officers, Forestry Commission district officers and the Committees of 7 at ward or village level who will help to verify the fires detected in their respective areas. Field verification (visits) or ground truthing was conducted to verify the presence or absence of identified fire points on the ground.

Statistical methods (Error matrix and McNemar's Test) are used for detailed analysis to determine the difference in performance of this algorithm and MSG products as recommended by Foody, (2004) and de Leeuw et al., (2006). The structure of the error matrix used is shown below:

Table 1: Error matrix (Manyangadze, 2011)

Fire Ground Date/Modis fire product

Fire Map	Fire	Y	N	Total
	Y			
	N			
	Total			

Y = Fire
N = No fire

The error matrix was used to calculate the commission (user's accuracy) and omission errors (producer's accuracy) as well as fires detected as a percentage of total fires. Non-fire areas were not considered when assessing the accuracy of each method with reference to MODIS fire product or ground data as they may bring bias in the accuracy level of the algorithm since the hotspots which indicate fires may not be common as compared to the non-fire areas. This is also supported by Longley et al., (2005) who pointed out that in some cases some classes are more common than others and a random sample that gives the equal probability for every parcel or pixel to be chosen may be inefficient as too many data may be gathered on common classes and not enough for the relatively rare classes. Therefore simple random sampling is not applicable in this study. The fire pixels from the two algorithms were compared with fire areas or points from the MODIS fire product or ground data.

The McNemar's test (1947) was used to test the hypothesis of this study as recommended by Foody, (2004) and de Leeuw et al., (2006). This method allows the comparison of the performance of the multi-temporal threshold algorithm and the MSG fire product. McNemar's test is based on 2 x 2 matrix as shown in table 2 below and the null hypothesis is that both algorithms (multi-temporal threshold algorithm and the MSG fire product) have same performance on detecting fires. Unlike in the error matrix described above the McNemar's test frequency table includes the no fire pixels since it is a comparison of two methods and these no fire pixels may be wrongly detected as fires by another algorithm.

Table 2: Cross tabulation of number of correct and wrongly classified pixels for two algorithms

Algorithm A	Algorithm B	
	Wrong	Correct
Wrong	f_{11}	f_{12}
Correct	f_{21}	f_{22}

The method uses a population ratio:

$$\psi = \hat{f}_{12} / \hat{f}_{21}$$

This is estimated by the simple ratio f_{21}/ f_{22} thus the null hypothesis equals Ho: $\psi = 1$. The method is based on the chi-square statistic that is computed as shown below:

$$x^2 = (f_{12} - f_{21})^2 / (f_{12} + f_{21})$$

The P-value of the McNemar's test is then used to reject or not reject the null hypothesis of equal performance of the multi-temporal threshold algorithm., The null hypothesis is rejected if the x^2 result is significant (p-value<0.05) with the degree of freedom (df) of 1 (with reference to the x^2test tables).

The data used in this study is independent of the data used in developing the multi-temporal threshold algorithm. This was to avoid biased accuracy assessment, however, the methods used in the first study (Portugal) (Manyangadze, 2011) are replicated in a different setting (Zimbabwe) so as to check for consistency and accuracy of the algorithm compared to the previous study.

3.3 Project implementation plan

An implementation plan (Fig 2 below) was developed based on the methods outlined above so as to achieve the objective of this study.

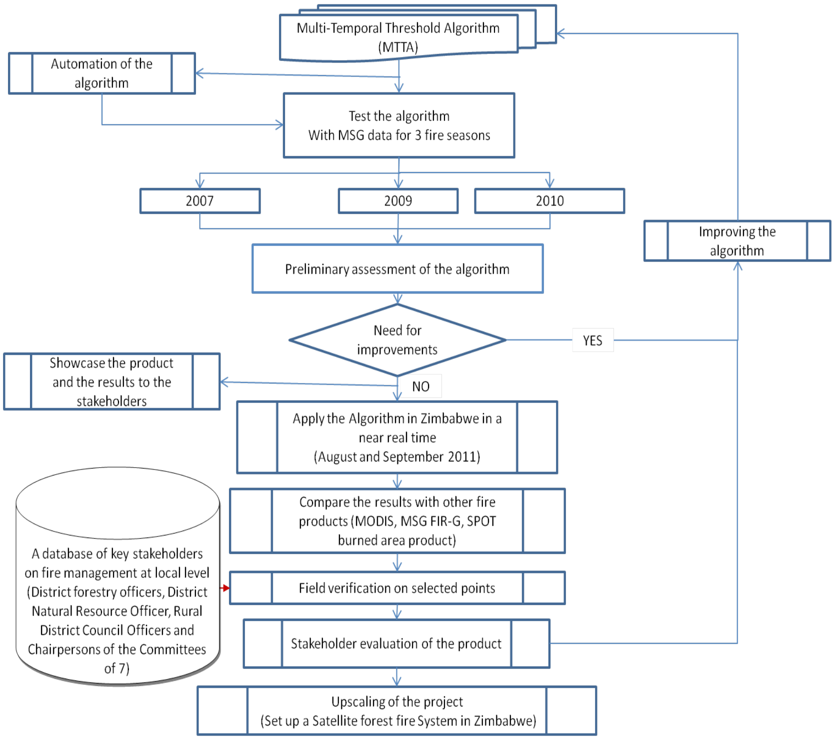

Figure 2: Implementation plan

As highlighted in section 1.4 above this study is focusing on the near-real time validation of the multi-temporal threshold algorithm in Zimbabwe, however, in order to obtain reliable results the method was tested for consistence and reliability using the data for 2007, 2009 and 2010 fire seasons before it was applied for 2011 (See Fig 2 above). This was designed to give confidence and the general idea on the performance of the algorithm compared to the MSG fire product contextual algorithm. This will allow the preliminary assessment of the performance of the algorithm and then applied to the 2011 fire season to allow near real-time validation and field verification of selected fire points and compare with MODIS and MSG fire products as well as SPOT burned area product. Several stakeholders including Environmental Management Agency (EMA), Forestry Commission, Rural District Councils and Committees of 7 will also participate in the assessment and evaluation of the algorithm.

4. Results and Analysis

This section presents the preliminary results of this study. The results presented below are mainly from the two tests of the algorithm picked from two fire seasons (2007 and 2009) in Zimbabwe.

4.1 Accuracy of the multi-temporal threshold algorithm

The maps below (Figure 3 and 4) are the test results of the multi-temporal threshold semi-automated procedure outlined in Figure 2 above compared to the MSG FIR-G with the MODIS fire product as the reference dataset. From these maps it could be noted that the multi-temporal threshold algorithm detected more MODIS fire points as compared to the MSG fire products (for error matrices refer to Appendix).

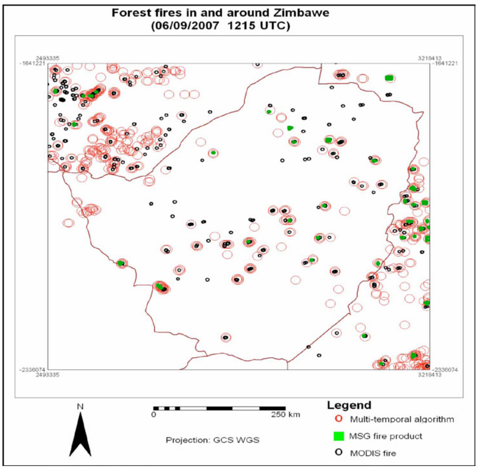

Figure 3: Forest fires in and around Zimbabwe (06/09/2007 - 1215UTC)

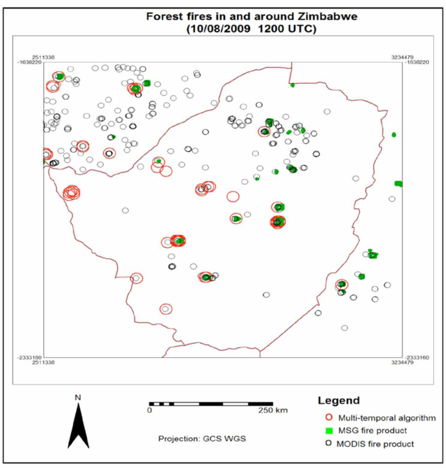

Figure 4: Forest fires in and around Zimbabwe (10/08/2009 – 1215 UTC)

The detailed analysis of the performance of the algorithms is shown in Table 3 and 4 below. The maps above show the fire points in and around Zimbabwe, however the analysis in the tables below consider those fire points in Zimbabwe.

Table 3: Accuracy of the algorithms: Multi-temporal threshold algorithm and contextual threshold algorithm (MSG FIRG product)

	Errors of commission (%)	Errors of omission (%)	Fires Detected (%)
Multi-temporal threshold algorithm	26.1	49.5	50.5
Contextual algorithm (MSG fire product)	16.1	75.9	24.1

Table 4: Frequency of correct and wrongly classified pixels by the multi-temporal threshold algorithm and contextual algorithm (MSG FIR-G product)

MSG fire product	Multi-temporal threshold algorithm		Total
	Wrong	Correct	
Wrong	48	35	83
Correct	19	20	39
Total	67	55	122

The results show that the multi-temporal threshold algorithm has a higher accuracy as it has correctly classified more fires compared to the contextual algorithm; this difference is significant (McNemar's test statistic (x^2) = 4.7, df = 1, p-value=0.0295) and reject the null hypothesis of no difference in forest fire detection rate between the multi-temporal threshold algorithm and MSG fire product. This result confirms the superiority of the multi-temporal threshold algorithm over the contextual algorithm as in the previous study when data from Portugal was used for development and validation of the algorithm (Manyangadze, 2011).

However, this is still at the preliminary stage of this study as more tests for 2010 and use of ground data as well as SPOT burned area products have to be incorporated to get the full analysis of the performance of the multi-temporal threshold algorithm.

5. Conclusions and Recommendations

It can be noted that the multi-temporal threshold algorithm has a high forest fire detection rate as compared to the MSG FIR-G contextual algorithm and there is a significant difference in the performance of these algorithms. However the near-real time validation that involves stakeholder participation still needs to be considered.

Based on the conclusion it can be recommended that stakeholders adopt the multi-temporal threshold algorithm as it performs better that the MSG fire product, however;

- More tests on the performance of the algorithms with reference to SPOT burned area product. This could give confidence and the possibility of this algorithm to be fully developed into a product.
- Near real time validation has to be emphasized as it uses the ground data that may be more reliable compared to other satellites products.
- Consider other indexes such as emissivity and check if it improves the performance of the algorithm

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Appendix

(a) Error Matrix for multi-temporal threshold algorithm, when it was individually assessed

Fire map (Multi-temporal threshold algorithm)	**MODIS fire product**			
	Fire	**Yes**	**No**	**Total**
	Yes	52	18	69
	No	51		
	Total	103		

(b) Error Matrix for multi-temporal threshold algorithm, when it was individually assessed

Fire map (Contextual algorithm (MSG FIRG))	**MODIS fire product**			
	Fire	**Yes**	**No**	**Total**
	Yes	25	5	31
	No	78		
	Total	103		

Frequency of two alternative methods (multi-temporal threshold algorithm and contextual threshold algorithm (MSG FIRG product)) compared against single MODIS fire product.

Ground truth	**Multi-temporal threshold algorithm**	**MSG FIRG product (Contextual algorithm)**	**Frequency**
Fire	Fire	Fire	20
Fire	Fire	No fire	32
No fire	No fire	Fire	3
Fire	No fire	Fire	5
No fire	Fire	No fire	14
Fire	No fire	No fire	46
No fire	Fire	Fire	2

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