Assessment and Analysis of Wildfires with the aid of Remote Sensing and GIS

By

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I declare that the Assessment and Analysis of Wildfires with the aid of Remote Sensing and GIS is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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Summary

Wildfires destroy large tracts of veld and forest land every year in South Africa. These fires can be devastating, resulting in loss of human lives, the destruction of property and the loss of income, for example the forest fire in the Sabie district in Mpumalanga in 2007 which destroyed about 7% of South Africa's forested areas. There are frequently legal disputes with respect to the origin of wildfires, the extent of the fire and the land cover destroyed by the fires.

The forensic capabilities of remote sensing in detecting and analysing post-wildfire characteristics have become an important contribution towards solving such legal disputes and in understanding wildfire characteristics. These post fire products can be used as evidence in court cases. Most of the time those court cases came up a few years after the fire event. By then, little or no evidence can be found on the terrain where the fire was. Remote sensing archives provide a reliable source of data that can be used to analyse these events after these long intervals.

The objective of this project is to highlight the methods used to generate these post-wildfire analysis products.

Key Terms

Wildfires, Post-wildfire, Remote Sensing, Veld fires, Landsat, AFIS, MODIS, National Veld and Forest Fire Act, Forensic, Disputes, Optical sensors

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Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

1.1 Background

"The catastrophic wildfires in Europe in 2009 and other great fires of recent years in Europe, Australia, South Africa and the USA are dramatic expressions not just killing forces unleashed, but of human folly" (Held, 2011). Held (2011) wrote about droughts that can lead to terrible fire weather conditions due to global warming. This could lead to unstoppable wildfires. Wildfires have a severe impact on the environment as much needed vegetation is destroyed. "… wildfires destroy millions of hectares of forests, woodlands and other vegetation, causing the loss of human and animal lives and immense economic damage, both in terms of resources destroyed and the cost of suppression." (FAO, 2007). This includes the loss of bio-diversity and the loss of soil fertility (Roy, 2010) that could lead to soil erosion and mudslides (Parsons and Orlemann, 2010).

Figure 1.1: Photo with the devastation of a wildfire. (Bonsor, 2010)

Wildfires also destroy vast expanses of veld and forest every year in South Africa. Uncontrolled fires can be very devastating (figure 1.1 and figure 1.2), causing the loss of human lives or the destruction of property which leads to loss of income. An example is the forest fire in the Sabie district in Mpumalanga in 2007 (Gordin, 2008) which destroyed approximately 7% of South Africa's forested areas. During that time the damage to the forests were estimated at R3.6 billion (Holtzhausen, 2011).

Figure 1.2: Animal suffering shortly after a fire

Fires usually start in very dry conditions, mostly in winter time in the summer rainfall areas in South Africa and during summer time in the Western Cape, a winter rainfall region. Most fires were started by humans and for various reasons, mostly due to carelessness (Bonsor, 2010).

The definition of remote sensing is the detection of a feature or object from a distance. Optical or passive satellite remote sensing obtains pictures of the earth from reflected and radiated energy that comes from the sun (Campbell & Wynne, 2011). These pictures can be interpreted to give more insight into what is happening on earth. Satellite remote sensing is like an "eye in the sky". In this study, emphasis was put on how optical remote sensing can assist to interpret and map wildfires.

The application of remote sensing in the detection and analysis of wildfires becomes more important for general communities. Remote sensing of wildfires can solve disputes on where a fire started, the spread thereof and the area destroyed, even years after the fire event. With remote sensing, the type of land cover (plantation that burned down or gazing veld that had been destroyed) can be determined.

1.2 Literature review

Satellites capture images on a daily basis. Those images are stored in an archive for later use. A fire event can only be studied after the event, because a satellite cannot be programmed to detect a fire ahead of time. An advantage of remote sensing is the fact that a fire can be analysed years after the event, as if it occurred only yesterday. A disadvantage is that the satellite might not have captured an image in that area during that period or it was too cloudy during that time.

The detection of satellite imagery before and after the fire event is called temporal resolution. This is based on the revisit time of the satellite, and revisit is the term used for visiting the same area on earth after some time. A high temporal resolution eases the analysis of fires. Spectral resolution is the amount of frequencies or wavelengths that are detected by a satellite sensor. The higher the spectral resolution, the easier it is to differentiate between the current fire scar and older scars and other objects, such as vegetation and water. With spatial resolution, the total area destroyed by a fire can be calculated. The higher the spatial resolution of a sensor, the more accurate the calculations can be.

Remote sensing can be used to monitor fires on a daily basis. One facility, Meraka (at the CSIR in South Africa), monitors wildfires on a daily basis by using the Advanced Fire Information System (AFIS). Other facilities where forest wildfires are monitored are the Global Fire Monitoring Centre (GFMC) in Germany (FAO, 2007) and the Global Observation for Forest and Land cover dynamics (GOFC-GOLD), an American company.

The AFIS system monitors all active fires greater than 50m in diameter on a daily basis in Southern Africa, South America and some parts of Asia. AFIS was developed by the CSIR in conjunction with the University of Maryland in the United States of America and was originally developed for Eskom. The AFIS system is based on the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor which is mounted on two satellites, Aqua and Terra, and the archive of this data dates back to 2004. It was developed for Eskom because the high voltage lines tripped during fires and it can have a financial impact on a town or city if there is no electricity. Eskom personnel needed to be informed at any time of the day where a fire broke out so that they could extinguish the fire before the lines tripped and the fire got out of control.

Remote sensing can also be used to map the extent (spatial resolution) of fires and the behaviour of such fires in order to calculate the spread thereof (temporal resolution) and the starting points. Fire scars can be successfully mapped with the aid of Landsat images (Chapter 4). For example, band four (TM4) of Landsat is especially useful since it detects the radiation of chlorophyll from healthy plants. Fires therefore will have a devastating effect or impact on the vegetation and this will cause a reduction in the infrared reflection. There will be a dramatic decrease in reflection values detected by Landsat band four but also an increase of the values in band seven (TM7) that corresponds to an increase in reflection of sunlight from exposed soil (Koutsias, *et al*, 2000; Lentile *et al,* 2006). By applying this principle, a burn ratio can be calculated with the use of band four and band seven of Landsat. A normalized burn ratio (NBR) is the following:

$$NBR = (TM4 - TM7)/(TM4 + TM7)$$

(Brewer *et al*, 2005; Henry, 2008; Lentile *et al*, 2006; Key & Benson, 2006). The burn ratio as well as the vegetation indice (NDVI) was used to determine the total fire scar and the severity thereof (Key, 2005). Those indices (see Chapter 4) as well as the spectral bands were used in combination in a supervised classification to determine the total burn scar. Older burn scars were subtracted from the newer scar to put the emphasis on the latter. The multi-temporal usage of Landsat was often used to map the severity of wildfires. For multi-temporal usage, the two scenes and the indices were subtracted from each other (Brewer *et al,* 2005; Key & Benson, 2006).

Other satellites, such as MODIS, SPOT and various high resolution satellites were utilized during this study. Even Google Earth was a great source of information.

Figure 1.3: Forest fire (Vaughn, 2013)

1.3 Motivation

The National Veld and Forest Fire Act (NVFFA) of 1998 of South Africa stated that firebreaks were needed to prevent the spread of a fire. “Every owner on whose land a veld fire might start or burn or from whose land it might spread must prepare and maintain a firebreak on his or her side of the boundary between his or her land and any adjoining land.” (NVFFA, 1998). The control of wildfires needed to be managed properly (Arpaci, *et al,* 2008; Romme, *et al,* 2006; Roy, 2010), and a management plan had to be in place. It is the responsibility of the landowner. If it is not properly managed, valuable grazable veld, plantations and property get destroyed. If fires were mismanaged, the effect thereof led to legal actions. The fires can be modelled to have a better understanding of the spread thereof (Finney, 1998; Kuntz & Karteris, 2010).

This study placed more focus on the forensic capabilities of remote sensing in order to solve disputes. A fire had to be analyzed to see where it started, what was destroyed and the spread thereof.

1.4 Research Problem

From an economical, socio-environmental and legal point of view, the impact of wildfires had and will most probably again in future have serious consequences on private and public properties and belongings.

1.5 Aim and objectives of the research

With the use of remote sensing, the aim of mapping of wildfires can be assessed and analyzed to determine the starting point, the spread thereof and the area that had been destroyed. The following three objectives were reached.

For the first objective, the determination of the fire scar, the following points were addressed:

- The location of the area impacted by the fire
- The determination of the satellite footprint for that area
- Acquisition of suitable and available satellite imagery
- Rectification of the imagery so that it could be used in a geo-information system (GIS).
- The classification of the imagery

The second objective was to locate where the fire started and the spread thereof:

- Determination of the AFIS archive information that corresponded to the fire scar
- Used the AFIS information to determine the starting point and the progression of the fire
- Local weather and wind data was also useful to determine the spread of the fire.

Thirdly, the area that had been destroyed was analyzed and the impact on the environment was determined:

- The classified imagery was vectorized and the total area was calculated.
- From the classified image, the grass and trees that had been destroyed was separated and the different areas were calculated.
- The total fire scar was broken up into pieces in order to determine the areas per farm that had been destroyed.
- Impact in terms of the loss in biomass as well as the destroyed property was assessed.

Figure 1.4: Forest fire on a mountain (Bonsor, 2010)

1.6 Study Area

This study was based on three case studies because of the variations in terrain, vegetation and the nature of the fire:

a) Case study 1 was based on a huge forest fire near Sabie in Mpumalanga in 2007 that destroyed about 7% of South Africa's plantations (Gordin, 2008). Three fires burned simultaneously at that time, one near Graskop, one near Sabie and one towards the south of Sabie. The vegetation consisted mostly out of commercial forest. That fire destroyed two saw mills and seven human lives were lost.

b) Case study 2 was based on a typical grass fire on the Highveld in Mpumalanga. Grass fires occurred on a yearly basis and a large portion of South Africa is covered with grasslands. These grass fires are common in Mpumalanga, Gauteng, the North West, Limpopo, KwaZulu-Natal, the Free State and the Eastern Cape.

c) Case study 3 was based on fires that burned into each other to create one common fire scar. Such fire scars needed to be analysed to determine which fire contributed to which part of the scar and then to determine where each of those fires started.

1.7 Data collection

Optical satellite imagery was used in all these case studies. The satellite imagery came mostly from Landsat 5, 7 and 8, SPOT 2, 4 and 5, and from the MODIS sensor. The reason why so many sensors were considered was that optical satellite imagery had limitations, such as:

a) Optical sensors cannot detect wildfires through clouds or thick smoke.
b) The sensors are in different orbits and do not detect the whole of South Africa every day. That means that only a portion of the country is photographed per day. Landsat revisited the same area every sixteen days and SPOT the same area every three to twenty-seven days. The MODIS sensor revisited the same area two to four times per day.
c) The resolution of the MODIS sensor is very low (500m) in comparison to the other satellites mentioned. Landsat has a resolution of 30m and SPOT has a resolution of 10m (SPOT 5) and 20m (SPOT 2 and 4).
d) The SPOT satellites are limited by the amount of spectral bands they have. Thus the spectral resolution is low. SPOT has only four multispectral bands in comparison to

the seven of Landsat. The spectral resolution of MODIS was not considered during this study.

e) The scan line corrector on board of Landsat 7 stopped functioning in 2003 and resulted in limited use of the data.

Higher resolution optical data had not been obtained for fire analysis due to the following reasons:

a) High resolution satellites are programmed more for urban areas.

b) High resolution data is very expensive.

c) A satellite cannot be programmed for a fire event.

d) The footprint or area covered by a high-resolution satellite is very small.

e) The spectral depth is mostly very shallow. The imagery in Google Earth was considered to determine the location of a fire event.

1.8 Research methodology

The fire analysis was based on qualitative research. Qualitative research focuses on the natural occurrence of a phenomenon and the complexity thereof. This research studies the natural content in the case study, but is limited to area and time (Hancock & Algozzini, 2006). This research is based on case studies (Baxter & Jack, 2008; Leedy & Ormrod, 2005) to put an emphasis on a specific methodology to map wildfires. With qualitative research and case studies, the methodology approached different angles to test fire investigations and the variations thereof.

The starting date of the fire event was important because it determined what satellite imagery could be used due to of the availability thereof. Not all the different satellite imagery was needed for a specific fire because not all data was available for that specified date. The selected data was orthorectified with the aid of an elevation model and a reference data set. The different indices were calculated and combined into one data set. With supervised classification the total area of the fire scar was determined.

The spread of all the fires were monitored with AFIS. The information was taken a day before the fire event up until a few days after the event. From this information the spread of the fire event was determined. The use of local weather data was very useful, especially wind data. That gave clarity on how the fire spread. With that information as well as the information of AFIS, the starting point of the fire was determined.

The satellite data was classified to separate new fire scars and old fire scars. The classification helped with the separation of trees and grass veld that had been destroyed. The classified image was vectorized and used in a geo-information system (GIS). In the GIS, the total area that had been destroyed was calculated as well as the areas of trees and grass. The destroyed areas per farm were separated in the fire scar.

In case study 1, Landsat 5 data was used. The spectral resolution of Landsat 5 was sufficient to analyse the fire. With the supervised classification, old fire scars could be separated from newer scars to eliminate the older scars. The spread of the fire was discussed and the starting point could be determined. The total area that had been destroyed by the fire was calculated.

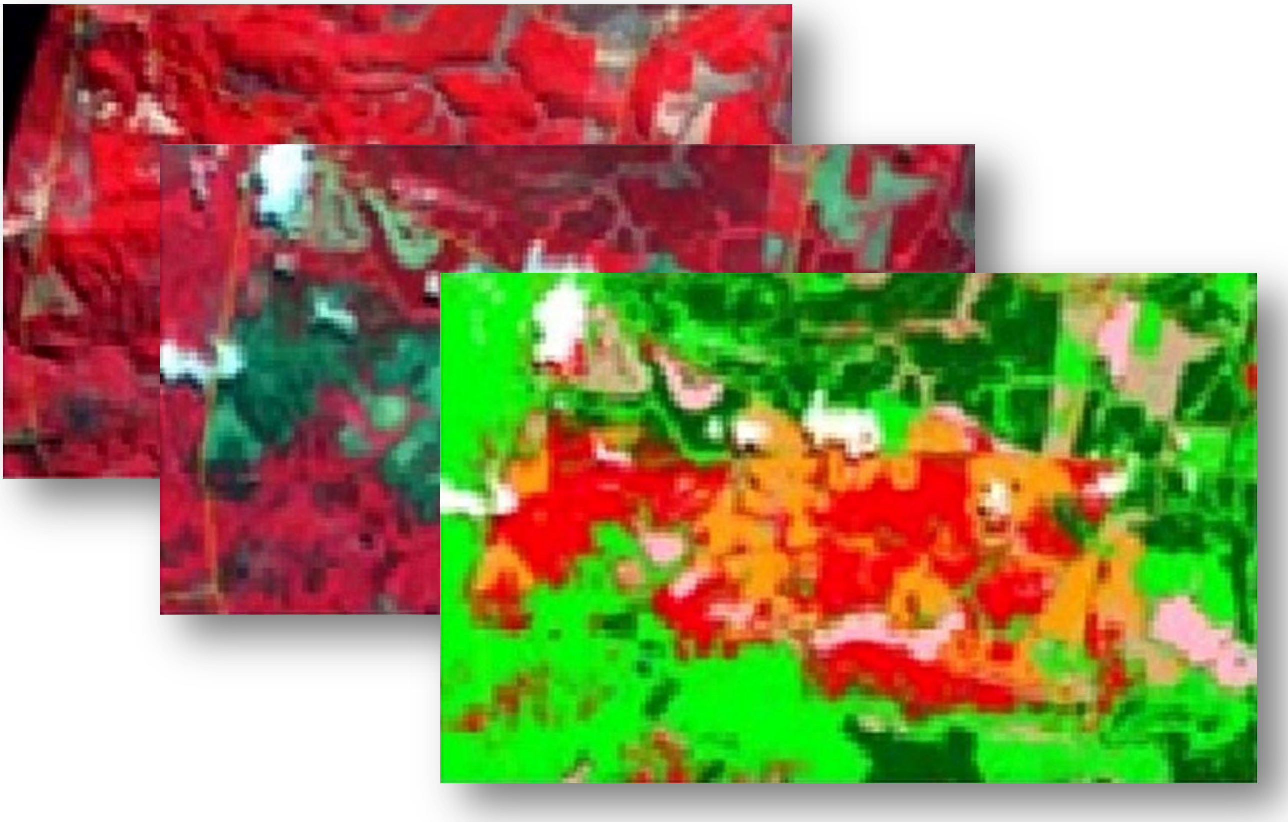

Figure 1.5: Before the fire, after the fire and a classification (Vorster, 2011)

The example in figure 1.5 indicates an area destroyed in a forested area, mostly plantations. The image on the left shows the forest before the fire and the image in the middle was taken shortly after the fire. The image on the right is a supervised classification to separate the burned trees from the burned grass (Vorster, 2011).

In case study 2, Landsat 5 data was also used. The example in figure 1.6 was based on case study 2 and it showed a grass fire that burned in a strong wind near Bethal in 2008. The starting point was easy to determine.

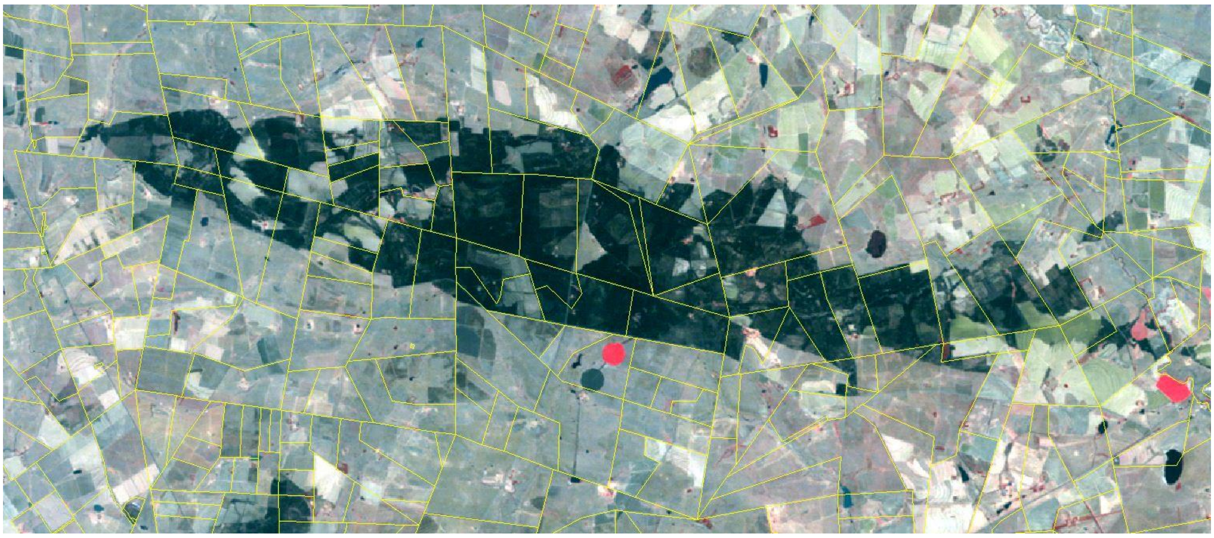

Figure 1.6: A fire scar originated from a strong wind (Vorster, 2011)

In case study 3, mostly MODIS data was used. A temporal resolution data set determined the spread of the fire. Landsat 7 was used after the event to calculate the total scar of the area that had been destroyed. With supervised classification, the older fires were separated from the newer fires.

Remote sensing can successfully be used to map wildfires. The use of optical satellites gave enough spatial resolution and spectral resolution to analyze a fire. In the following chapters the method will be discussed in more detail.

Chapter 2: Literature Study

2.1 Introduction

Fire is a natural phenomenon, though large areas of veld and forests are destroyed every year in South Africa, causing damage to infrastructure and sometimes even the loss of people's lives. Fires can be used to control invader species, encourage new growth to vegetation and change soil characteristics (Goslar, 2006). The ignition of wildfires was primarily due to lightning or caused by humans. To prevent fires from growing disastrously and becoming uncontrollable, they need to be minimized and managed.

For the effective management of veld fires, laws need to be in place to map out the different rules and regulations applicable. Fires can be detected, monitored and analyzed with the aid of remote sensing. In this chapter the use of remote sensing for fire analysis and the National Veld and Forest Fire Act no. 101 of 1998 will be discussed. This literature study will also include the reason for fire protection associations as well as their duties, fire danger rating systems, fire prevention and fire fighting. Fires within an urban environment are excluded from this act (DWAF, 2005).

2.2 Veld fires in South Africa

Wildfires destroy large stretches of veld and forest every year in South Africa. Fires often become devastating through the destruction of property, livestock, homesteads and plantations (DWAF, 2005; Forsyth *et al*, 2010). That includes loss of income (Moses, 2011) and even the loss of human lives, for example the forest fire in the Sabie district in Mpumalanga in 2007 (Gordin, 2008) which destroyed about 7% of South Africa's forested areas. Another example is that fire endangers people that are living below the bread line, the very poor (Forsyth *et al*, 2010; Procter, 2011), because those people depend on the ground they live on. The “Working on Fire”, a job creation initiative of the government, extinguishes many fires every year (Forsyth *et al*, 2010) to limit the spread of wildfires.

Fires in the grass biomes such as the Free State, Gauteng, KwaZulu-Natal and Mpumalanga and in the fynbos biome in the Western Cape occurred on a regular basis. More than 240 000 hectares of grass veld is destroyed every year in the Free State alone (Procter, 2011). Forest fires also occurred on a regular basis and their economic losses are well documented (Forsyth *et al*, 2010). Only a limited number of studies on wildfires have been done in South Africa. This includes an experimental study in the Kruger National Park after five people lost their lives during a veld fire in September 2001 (Forsyth *et al,* 2010). The study was based on how to avoid such disasters through fire management with the identification of biomass and the creation of firebreaks.

2.3 Reason for a Fire Act

According to the Conservation of Agriculture Resources Act No 43 of 1983, the loss of biodiversity (DWAF, 2005; Forsyth *et al,* 2010; Procter, 2011) and the loss of soil fertility (Roy, 2010) can lead to severe soil erosion and mudslides (Parsons and Orlemann, 2010) and needs to be prevented or at least minimized and managed. To prevent fatalities as mentioned above, an act had to be put in place. “The primary purpose of this Act is to prevent and combat veld, forest and mountain fires throughout the Republic.” (NVFFA, 1998). Veld fires also have a negative impact on the air quality (DWAF, 2005; Lentile *et al,* 2006).

2.4 Fire Protection Associations (FPA)

“Owners may form an association for the purpose of predicting, preventing, managing and extinguishing veldfires …” (NVFFA, 1998). Fire Protection Associations (FPA’s) are voluntary associations (DWAF, 2005; NVFFA, 1998) that comprises of landowners in areas that are prone to fire events. The reason for establishing an FPA is to have an organization that can coordinate a community initiative to prevent and fight veld fires, as large fires cannot be stopped by individual effort (Moses, 2011) and therefore a team effort is needed. "…, the defendant is presumed to have been negligent in relation to the veldfire until the contrary is proved, unless the defendant is a member of a fire protection association in the area where the veldfire occurred." (NVFFA, 1998). It is important to determine the starting point of a wildfire in order to prove negligence.

FPA's are established in those areas where fires occurred regularly, areas that have a high risk of fires, areas where the vegetation is uniform, or where the climate conditions are of such a nature that a fire might occur (Moses, 2011; NVFFA, 1998). Some of the advantages of an FPA are the benefits of cooperation in a team as well as minimizing costs, because the fire fighting equipment belongs to the FPA and not to the individual. One of the duties of such an FPA is to have a fire management strategy and an agreement in place (DAWF, 2005) if a fire crosses boundaries. The members are bound by rules of the management of fires and the prevention thereof (NVFFA, 1998). The members will also have access to education, training and advice in fire fighting (Procter, 2011).

The NVFFA specifies that landowners have to take precautions to prevent fires and to extinguish them (Moses, 2011). The rules include the minimum standard for the readiness in case of a fire ("The rules must provide for … members in relation to all aspects of veldfire prevention and readiness for fire fighting." NVFFA, 1998) and the guidelines for controlling burning to reduce the danger of fires ("… controlled burning to conserve ecosystems and reduce the fire danger …" NVFFA, 1998).

2.5 Fire Danger Rating

According to the NVFFA, there must be a fire rating system on a national scale. These updates can come from FPA's, the Weather Bureau of South Africa and consultation companies. The fire rating system indicates the fire risk areas. When the risk is very high (red), no open fires are allowed (NVFFA, 1998). A fire danger index is created on a daily basis from the Moderate Resolution Imaging Spectroradiometer (MODIS) imagery in the Advanced Fire Information System (AFIS).

The fire danger system takes the following factors into account: topography of the area; the type of vegetation; the seasonal climate, typical and recent, and the current and forecasted weather conditions (NVFFA, 1998). The danger of veld fires expanded rapidly in dry, warm conditions and the risk expanded (Forsyth *et al*, 2010). The fire risk is higher in years of drought (Procter, 2011) or during the winter months in the summer rainfall areas. Savannah and grasslands are the most prone to veld fires.

Figure 2.1 is a fire danger map of South Africa. The fire danger map takes the biomes and climate into consideration. A fire danger map, such as in figure 2.1, can be derived from The Advanced Fire Information System (AFIS) on a daily basis, as well as from satellite imagery (Frost, 2012).

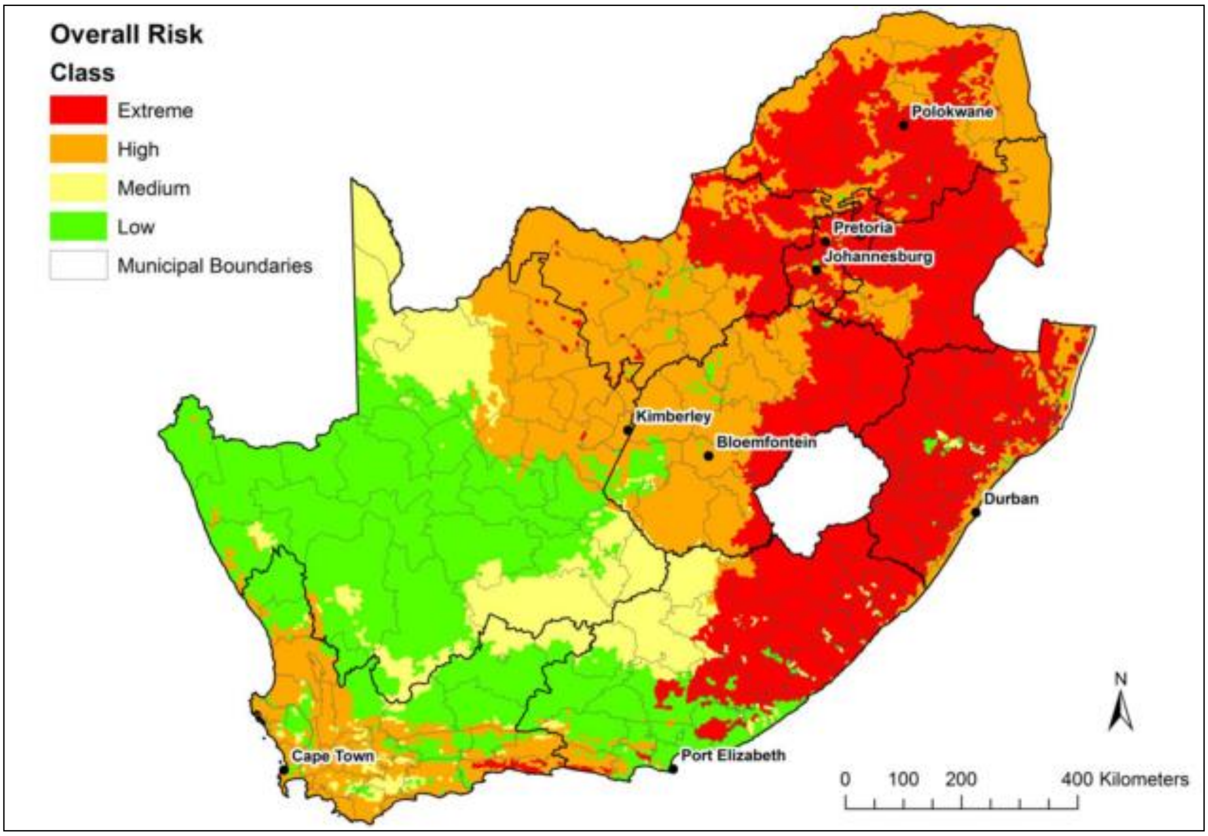

Figure 2.1: A fire danger map of South Africa (Moses, 2011)

2.6 Fire prevention through controlled fires

The National Veld and Forest Fire Act of 1998 (NVFFA) of South Africa stated that firebreaks are needed to prevent the spread of a fire, as a fire does not respect boundaries. A firebreak is an area or strip where flammable material is removed in order to minimize or prevent a fire from developing into a raging wildfire. A firebreak does not stop a raging fire but minimizes the effect thereof. It is the responsibility of the landowner to take precautions to prevent veld fires (Moses, 2011; NVFFA, 1998). To create a firebreak, the following needs to be taken into consideration:

- A firebreak needs to be wide enough to stop a reasonable fire. The NVFFA did not prescribe the width of a firebreak; the width depends on the risk of a fire breaking out.
- A firebreak must not cause soil erosion.
- A firebreak must be relatively free of flammable material (DWAF, 2005).
- A firebreak must not be created in areas where there are endangered plants.

Figure 2.2 is an example of firebreaks that were created in an area close to Belfast in Mpumalanga. The data came from the SPOT (Le Système Pour l'Observation de la Terre) 4 satellite and was taken on 30 July 2011. On the bottom left hand corner is the town of Belfast. The green areas indicate plantations, the pinkish areas are grasslands and the dark maroon areas are burn scars, which include the dark maroon lines (firebreaks). On the right hand side is a zoom-in of a part of the image to show the firebreaks more clearly.

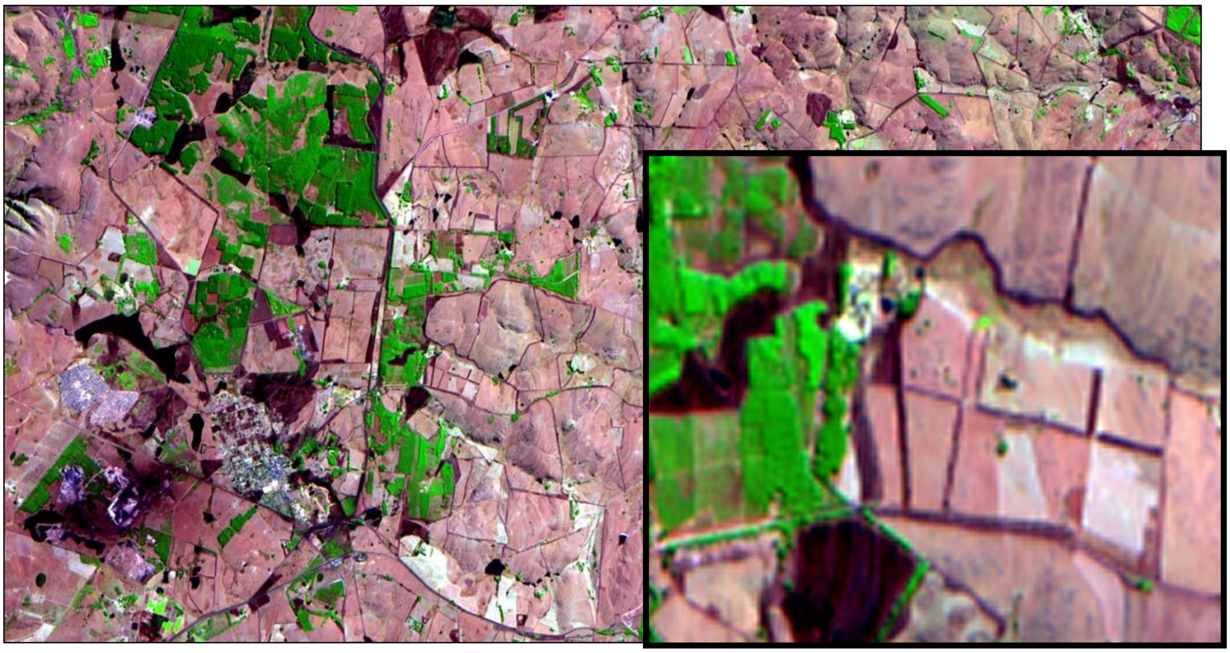

Figure 2.2: This is a SPOT 4 image taken on 30 July 2011. On this image firebreaks are clearly visible.

A firebreak may also be in an area that allows it, like grassland (NVFFA, 1998). Almost no firebreaks are created in the Karoo because of the harsh climate and the sparse vegetation. Before creating a firebreak, the landowner and his/her neighbour must decide on a date and then the firebreak will be created on the border. A firebreak cannot be created in an area when the fire risk is very high (DWAF, 2005).

A fire management plan must be in place to control wildfires (Arpaci, *et al*, 2008; Romme, *et al,* 2006; Roy, 2010). If fires are not properly managed (Valese, *et al*, 2011), valuable pastureland, plantations and property will be destroyed. If fires are mismanaged, the effect thereof can lead to legal actions (NVFFA, 1998).

2.7 Other factors that have an influence on veld fires

For a fire to burn, the following components are required: fuel or vegetation, suitable weather conditions and topography (Finney, 1998; Goslar, 2006; Steensland *et al*, 2005). In short, it needs heat, fuel and oxygen (Bonsor, 2010). When doing fire modelling, all these three components are considered. This study does not address fire modelling.

Biomass or fuel plays a big role in fires. The more biomass there is to burn, the larger the fire. Biomass is the vegetated organic matter (Goslar, 2006). The spread of fires depends on the continuity of the fuel (Goslar, 2006). The moisture content of the fuel plays a bigger role in the ignition of the fire. The dryer the fuel, the easier it ignites.

Weather also plays a significant role in veld fires. Factors such as wind, humidity and temperature have an effect on fires (Bonsor, 2010). High temperatures, low humidity and wind increase the fire danger. A fire burns in three primary directions. A head fire burns down wind, a back fire burns against the wind and flank fires burn to the sides (Goslar, 2006). Wind supplies oxygen to a fire and makes it burn faster. With wind, fire burns in an oval shape (Finney, 1998; Köse *et al,* 2010). The stronger the wind, the more elongated the shape will be (figure 1.6) with very little back burn. With no wind, the shape will be rounder (Steensland *et al,* 2005) with a lot of back burn.

Topography also plays a role. A fire burns faster up a slope than down a slope. The steeper the slope, the faster it burns up-slope (Bonsor, 2010). The rate at which it burns up the slope can be calculated with the following equation:

$$R=R_0e^{bx}$$

R represents the speed of the fire (m/s), R_0 the speed of the fire on horizontal ground (m/s), b is a constant of b = 0.0693 and x is the slope in degrees (Goslar, 2006). A fire needs oxygen to burn and warm air rises. When a fire burns uphill, it is easy to get oxygen and as a result, the fire burns faster. If a fire burns downhill, it burns slower, because the uptake of oxygen is more difficult.

2.8 What is remote sensing and the application thereof

Remote sensing is the measurement of characteristics such as radiation or reflection from objects on earth by either satellites or aircraft (Avery & Berlin, 1992; Campbell & Wynne, 2011; Mather, 2004). With remote sensing, areas can be imaged or photographed in any part of the world, even in remote areas. Remote sensing can also be used to detect and monitor disasters and hazards like wildfires (Joyce *et al*, 2009). Satellite remote sensing gets to remote areas quicker than aircraft remote sensing.

These characteristics are measured in different wavelengths from the electromagnetic spectrum (EM). The behaviour of these wavelengths from each object is the spectral signature (Mather, 2004). The spectral signature of each object differs from the next and it is sometimes difficult to differentiate between different objects (Avery & Berlin, 1992; Campbell & Wynne, 2011). For example, the spectral signature of vegetation with a lot of chlorophyll looks different from that of bare soil, and the spectral signature of water is also different (figure 2.3).

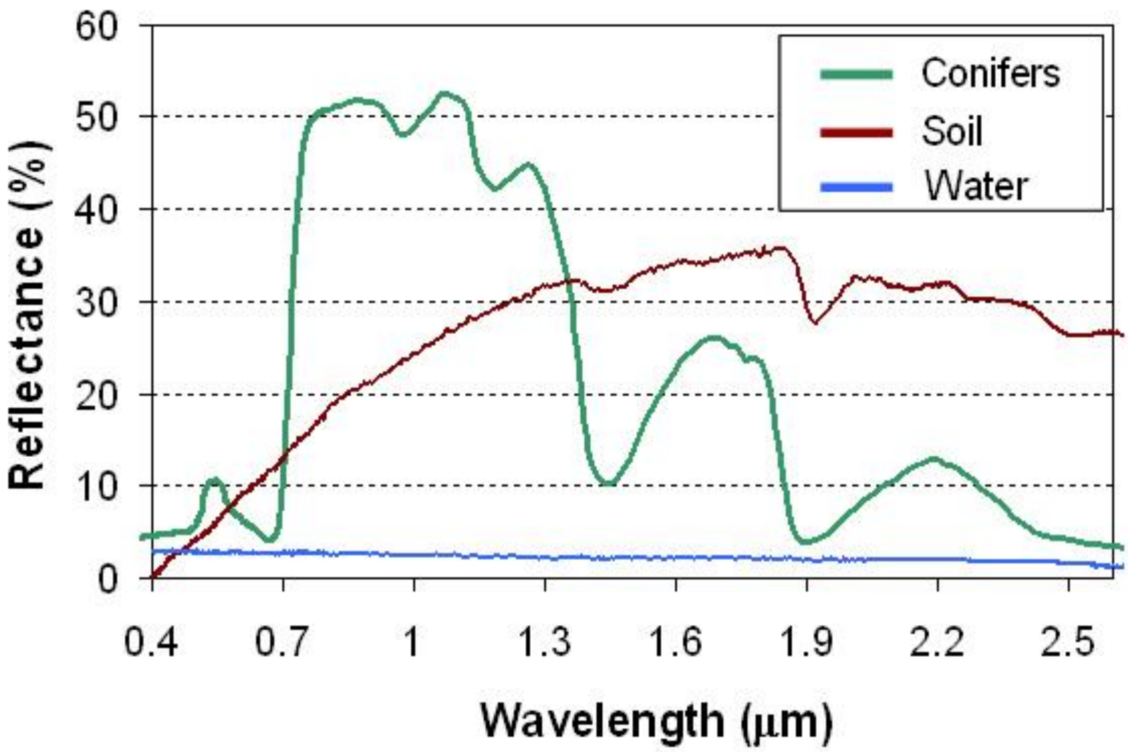

Figure 2.3: Spectral signatures of different objects (Barrosos & Montiero, 2010)

The EM can be divided into bands with similar characteristics (Avery & Berlin, 1992) called spectral bands. A satellite image detects some of those bands to obtain the spectral signatures of the objects. True colour bands (from 0.4 to 0.7µm), being the red, green and blue bands on the electromagnetic spectrum (Avery & Berlin, 1992; Campbell & Wynne, 2011), does not give enough information to do a fire analysis (figure 2.4). False colour combinations gave more definition to certain objects, based on their spectral radiation (figure 2.5). Most satellites have enough spectral bands for fire investigations.

The spectral signature of green vegetation has two peaks. The first peak of the vegetation is the chlorophyll absorption in the visible red band (0.5µm), and the second peak of the vegetation is in the near-infrared band (0.8µm), due to the structure of the cells in the leaves of vegetation (Campbell & Wynne, 2011; Girard & Girard, 2003). Fire has a huge effect on the vegetation and destroys chlorophyll (Epting *et al*, 2005) and the structures in the vegetation, which means that the radiation value in the near infrared decreases.

Figure 2.4: A subset of a Landsat image in true colour. The image was taken on 23 February 2012 near Citrusdal in the Western Cape.

Figure 2.4 is a Landsat image in true colour with the band combination 3,2,1 as red, green and blue. The chlorophyll radiation of the vegetation on the mountains and the vegetation in the valleys look the same. The dark areas are mountainous areas and the light brown areas are agricultural fields. No or little difference can be seen between the vegetation and the water bodies (dams).

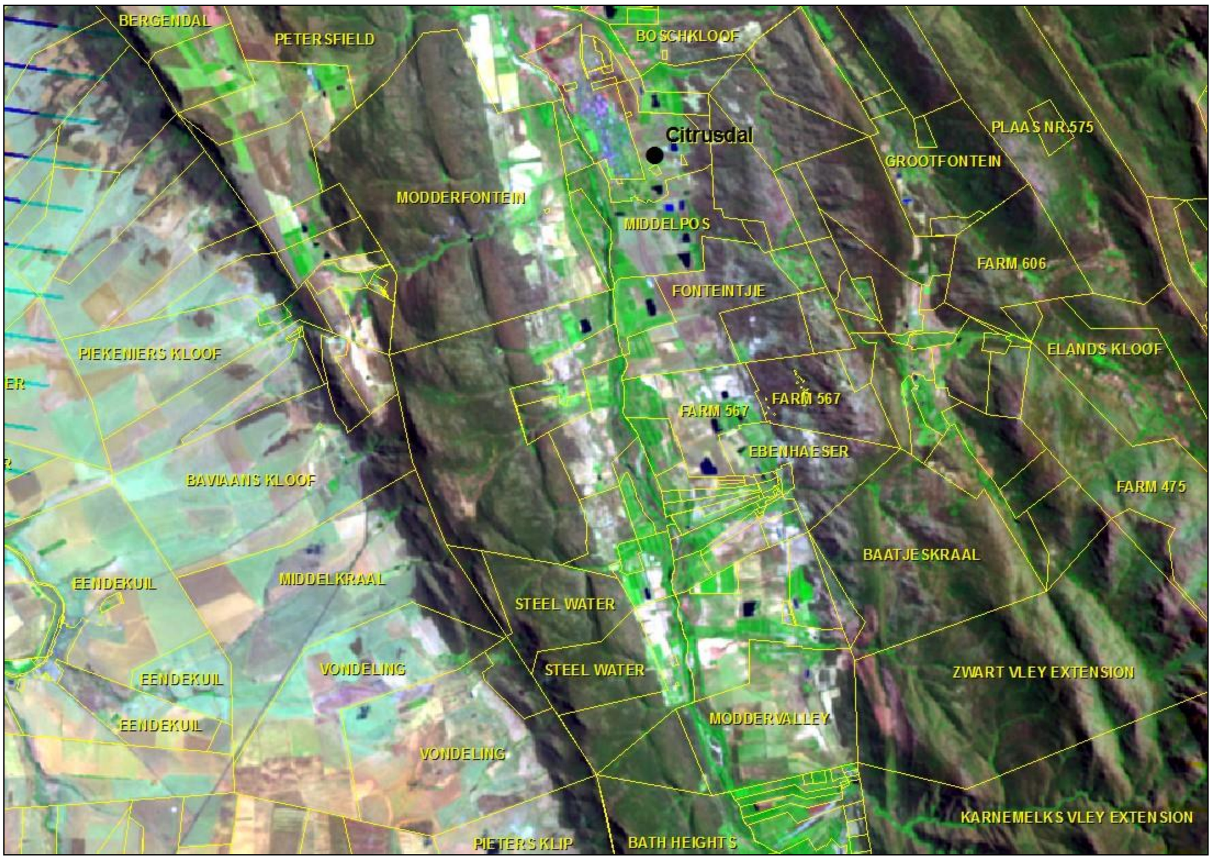

Figure 2.5: A subset of a Landsat image in false colour. The image was taken on 23 February 2012 near Citrusdal in the Western Cape.

Figure 2.5 is the same Landsat image as in figure 2.4, but in false colour with the band combination of 7,4,2 as red, green and blue. The high chlorophyll vegetation is indicated by the bright green and the lower chlorophyll vegetation by the darker greens. The water bodies showed up in dark blue spots. The turquoise on the left on the agricultural fields indicates some vegetation.

2.9 Remote sensing for fire analysis

A fire event has to be photographed as soon as possible. To send up a plane for every fire is very expensive and impractical. Satellite remote sensing is more economical and reliable than aerial photography, especially in post-fire analysis. The applications of aerial photos shifted more to high resolution applications (Thurston, 2010). If an area is damaged by a fire and it requires a rapid investigation, then an aerial photo can be taken.

Satellites revisited the same area on a regular basis. That means that the area destroyed by the fire will be imaged within three to thirty days after the event. A good temporal resolution is therefore possible.

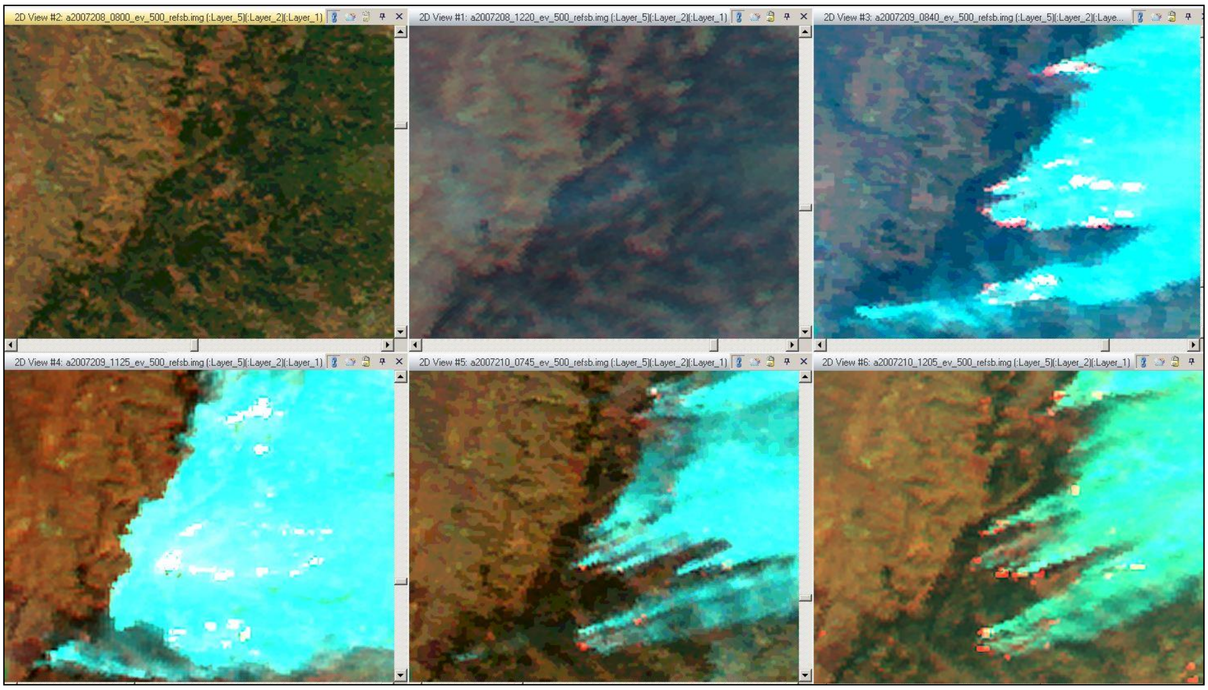

Figure 2.6: An example of a time series to track a fire.

Figure 2.6 gives a time series of the Sabie fire in 2007. The images are from the MODIS sensor. This time series provides information about the fire for the first three days (two acquisitions of MODIS data per day). There are no fires on the first and second images, although smoke is visible on the second image. On the third image in the upper row, a few large fires are visible and it is followed by the other images. These images indicate that a fire can be detected and also tracked as it burns. It is not always possible to track a fire, as seen in the example in figure 1.6. In the Free State, a fire can start and burn between two acquisitions from the MODIS sensor. The presence of clouds can also be a handicap in the detection of a fire by a satellite (Procter, 2011).

Figure 2.7 is a Landsat image that covers the same area as figure 2.4 and figure 2.5 and it indicates a clearly visible fire scar in the centre of the image, indicated by the reddish colour. The band combination in figure 2.7 is the same as in figure 2.5. The lines on the left of the image are the effect of the malfunctioning scan line corrector of Landsat 7.

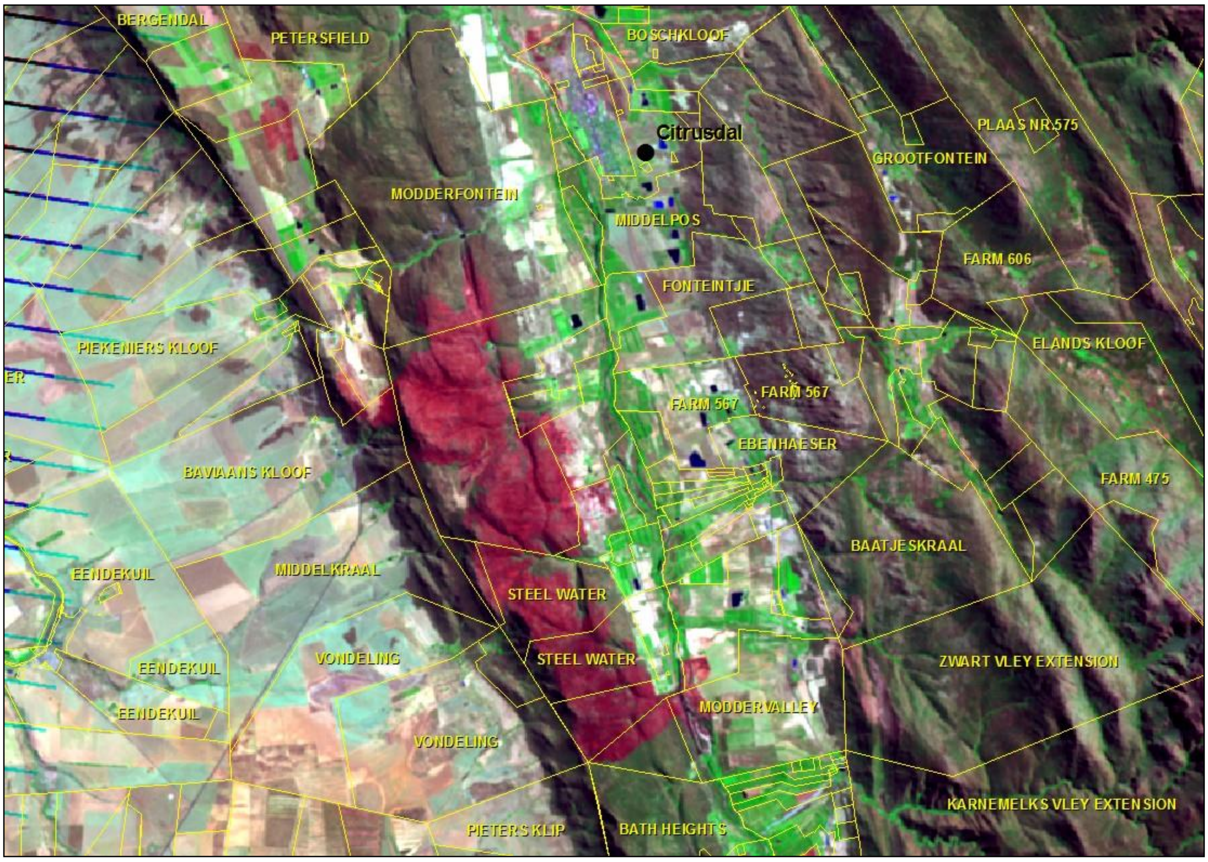

Figure 2.7: A subset of Landsat on 10 March 2012

Apart from temporal resolution, spatial resolution also plays a huge role in the analysis of wildfires. With a low resolution, fire scars can be detected, but the analysis thereof is a bit constrained. The medium resolution, which varies from 5m to about 50m, works well for fire scar analysis. Low resolution varies from about 200m to 5km. The Landsat image in figure 2.7 has a medium resolution of 30m. The image in figure 2.8 is from the MODIS sensor, a low-resolution sensor, with a resolution of 250m. The image in figure 2.8 covers the same area as in figure 2.7. The fire scar is visible but not as clearly as in figure 2.7. Only a few of the clearly visible features in figure 2.7 can be identified in figure 2.8, due to the low resolution.

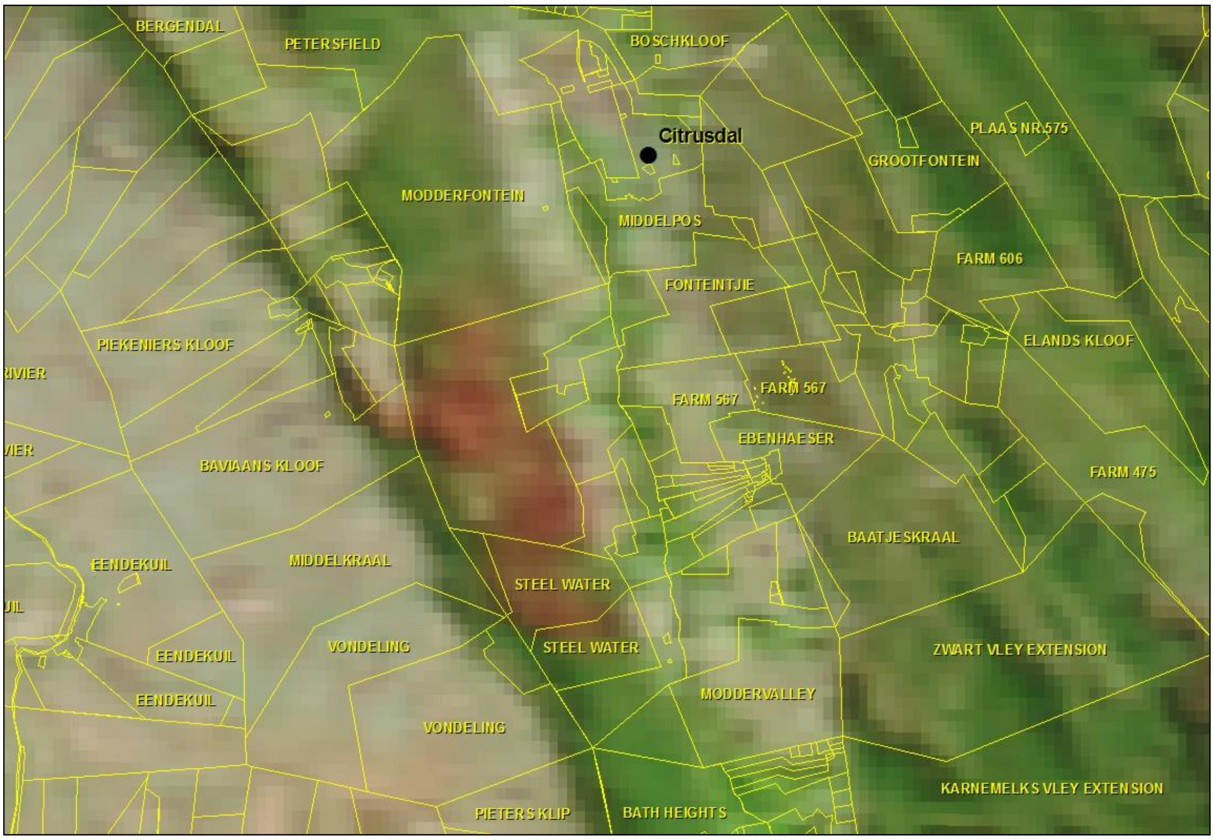

Figure 2.8: A subset of a MODIS image of 13 February 2012

Chapter 3: Methodology

3.1 Introduction

The fire analysis was based on qualitative research. Qualitative research focuses on the natural occurrence of a phenomenon and the complexity thereof. Qualitative research is the study of the natural content in a case study, but limited to area and time (Hancock & Algozzini, 2006). This research was based on case studies (Baxter & Jack, 2008; Leedy & Ormrod, 2005) to put emphasis on a specific methodology to map wildfires. With qualitative research and case studies, the methodology approached different angles to test fire investigations and the variations thereof.

The methodology study on wildfires was based on three case studies. The first case study was choose to apply this methodology in a forest fire, the second for a grass fire and the third for a special case of grass fire, where fires burned into each other. These case studies will be explained accordingly to the processes this methodology (figure 3.1).

The mapping of wildfires was assessed and analyzed to determine the starting point, the spread thereof and the area that had been destroyed. The following three objectives were reached.

For obtaining the first objective, the determination of the fire scar, the following points were addressed:

- The location of the area impacted by the fire.
- The determination of the satellite footprint for that area.
- Acquisition of suitable and available satellite imagery.
- Rectification of the imagery so that it could be used in a geo-information system (GIS).
- The classification of the imagery.

The second objective was to locate where the fire started and the spread thereof.

- Determination of the AFIS archive information that corresponded to the fire scar.
- Used the AFIS information to determine the starting point and the progression of the fire.
- Local weather and wind data was also useful to determine the spread of the fire.

Thirdly, the area that had been destroyed was analyzed and the impact on the environment was determined.

- The classified imagery was vectorized and the total area calculated.
- From the classified image, the grass and trees that had been destroyed were separated and the different areas were calculated.
- The total fire scar was broken up into pieces to be able to determine the areas per farm that had been destroyed.

The impact in terms of loss in biomass as well as destroyed property was assessed.

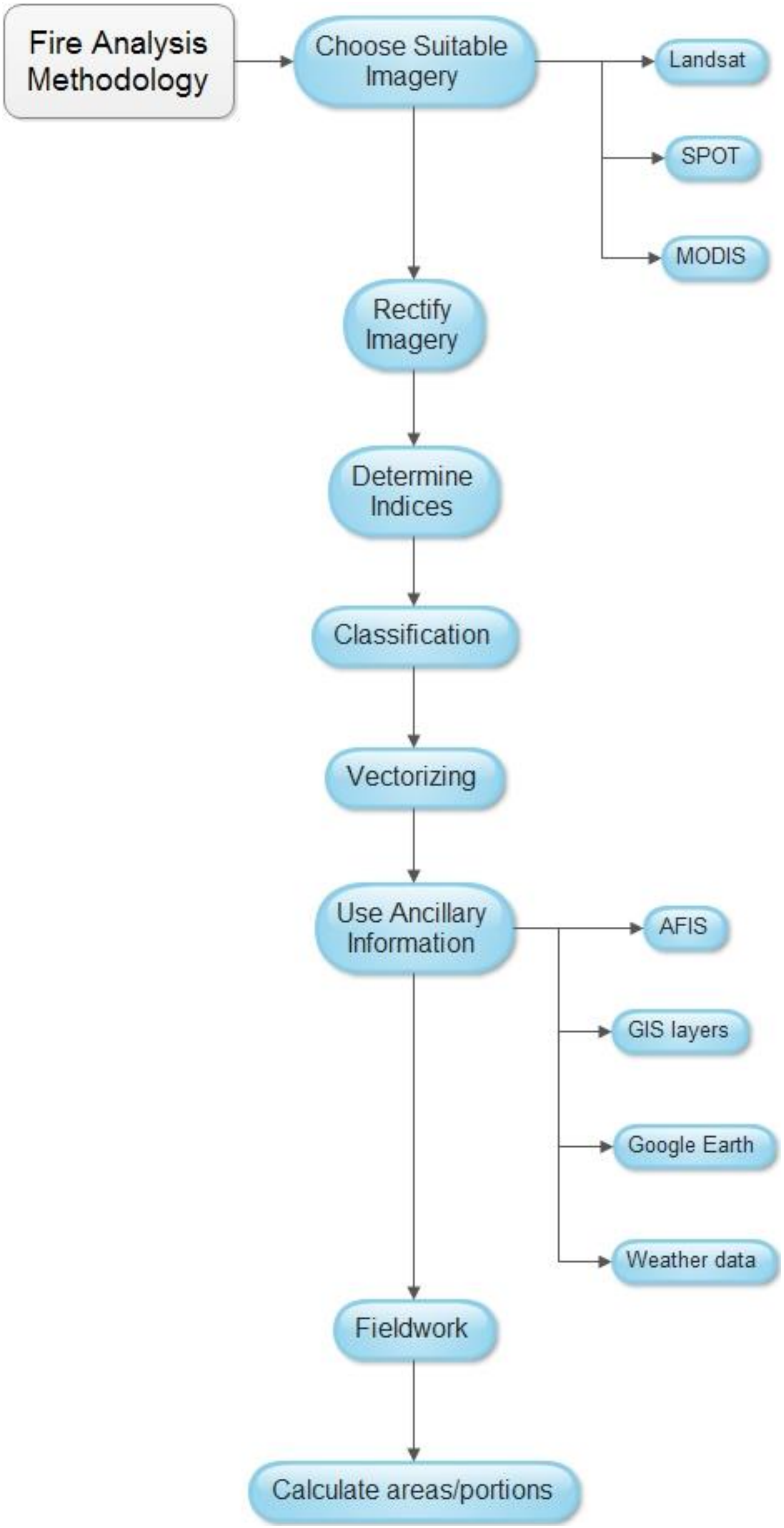

Figure 3.1: Flow diagram to do a fire analysis

3.2 Choice of suitable imagery

A fire event happened on a specific date. The choice of sensor that is used to analyse the impact depends on that specific date. The sensor of choice is based on optical satellite data, but it has a few limitations, such as:

- Optical sensors cannot detect wildfires through clouds or thick smoke.
- Low spatial resolution sensors such as the Moderate Resolution Spectroradiometer (MODIS) and the satellites of the National Oceanic and Atmospheric Administration (NOAA) have a satisfying temporal resolution. The spatial resolution of the MODIS sensor varies from 250m (for two bands) and 500m (for five bands) to 1km (for the remaining twenty-nine bands) and the resolution of NOAA exceeds 1km. Low resolution satellites revisit the same area often (they have a high temporal resolution), but no detail analysis can be done. With medium resolution sensors on satellites such as Landsat, SPOT and Resource Sat, a better spatially accurate analysis can be achieved. Landsat has a resolution of 30m and SPOT has a multispectral resolution of 10m (SPOT 5) and 20m (SPOT 2 and 4). Resource Sat has a 50m resolution. There are a number of high resolution sensors, which include Ikonos (0.8m), GeoEye (0.6m), QuickBird (0.5m), WorldView (0.5m) and RapidEye (0.6m). These high resolution satellites do not revisit the same area on a regular basis and are therefore not suitable to use in fire analysis.
- The sensors orbit in different orbits and do not detect the whole of South Africa every day. That means that only a portion of the country is photographed or scanned per day. Landsat revisits the same area every sixteen days and SPOT revisits the same area every three to twenty-seven days. The MODIS sensor revisits the same area two to four times per day. The high resolution satellites cannot be utilized to scan the whole path because the amount of data will be too much to archive and therefore only a limited amount of datasets are available on fire scars. A satellite cannot be programmed ahead of the time to detect a fire; therefore fire analysis can only be done on archived data.
- The Le Système Pour l'Observation de la Terre (SPOT) satellites are limited by the amount of bands they have; the spectral resolution is low. SPOT has only four multispectral bands in comparison to the seven of Landsat. The spectral resolution

of MODIS is thirty-two bands but was not considered because of the low resolution.

- The scan line corrector on board of Landsat 7 stopped functioning in 2003 and resulted in limited use of the data.
- A fire scar can still be analyzed for one or two months after the event as long as the analysis is done before the start of the raining season. When the raining season starts, the burnt grass will grow back and will look similar to the areas that were not destroyed.

For this research on fire analysis, more emphasis was put on the use of medium resolution satellites such as Landsat and SPOT. MODIS data was mainly used as a backdrop to indicate the progress of the fire event.

3.3 The suitability of Landsat data for fire analysis

The spectral resolution (seven bands) and spatial resolution (30m) of Landsat 5 and Landsat 7 were sufficient to analyse a fire. Fire scars were successfully mapped with the use of Landsat data because fire has a devastating effect on vegetation, which reflects highly in band four (TM4). TM3 detects the absorption of sunlight active chlorophyll. TM4 detects radiation of the cell structure within the plants and the plant vigour (Campbell & Wynne, 2011). A fire therefore causes a reduction in the reflection in TM4 and increases the reflection of soil exposure (Koutsias, *et al,* 2000; Lentile *et al,* 2006), which is detected by band seven (TM7). Figure 3.2 indicates the electromagnetic spectrum and the bands can be compared.

The Landsat 5 satellite has the following spectral bands:

Band1: (Blue, 0.45-0.52µm)
Band2: (Green, 0.52-0.60µm)
Band3: (Red, 0.63-0.69µm)
Band4: (NIR, 0.76-0.90µm)
Band5: (SWIR, 1.55-1.74µm)
Band6: (Thermal IR, 10.40-12.50µm)

Band7: (SWIR, 2.08-2.35µm)

(Campbell & Wynne, 2011; Girard &Girard, 2003)

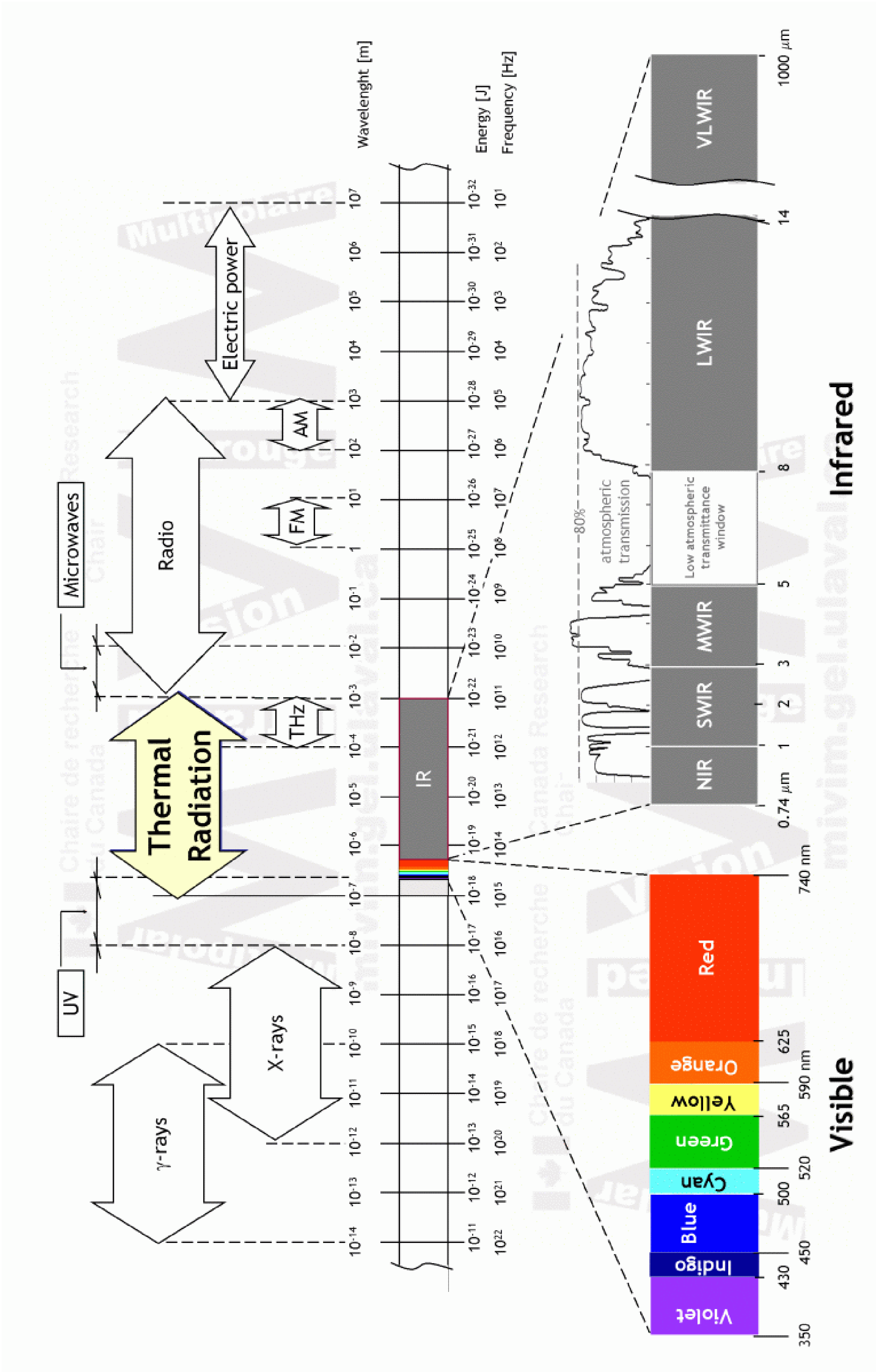

Figure 3.2: Electromagnetic Spectrum (Castenedo, 2005)

3.4 The suitability of SPOT data for fire analysis

The spectral depth (four bands) of SPOT is not as deep as that of Landsat. The panchromatic band (or black-and-white band) was not utilized during the veld fire research because the fire cannot be analysed with panchromatic data. The panchromatic band has a higher resolution than the other bands, but is captured from the radiation of the total visible light area of the electromagnetic spectrum (0.51µm - 0.73µm) (Campbell & Wynne, 2011). The spatial resolution of SPOT 4 is 20m and SPOT 5's is 10m.

The wavelengths of the multispectral bands of SPOT 4 and SPOT 5 are the same, except for the spatial resolution of 20m for SPOT 4 and 10m for SPOT 5. SPOT 2, as well as the other bands, does not have a short-wave infrared (SWIR) band. Figure 3.2 indicates the electromagnetic spectrum and the bands can be compared.

SPOT has the following multispectral bands:

Band1: (Green, 0.50-0.59µm)
Band2: (Red, 0.61-0.68µm)
Band3: (NIR, 0.79-0.89µm)
Band4: (SWIR, 1.58-1.75µm)

(Campbell & Wynne, 2011; Mather, 2004)

3.5 The suitability of MODIS data for fire analysis

No analysis was done on the MODIS data, but MODIS data was utilized to keep track of the progress of the fires because of the high revisit times of the sensor. MODIS also formed the backbone of the AFIS system. The resolution of this sensor is too low to do detailed fire analysis. It has two bands at a resolution of 250m, five bands at 500m and twenty-nine bands at a resolution of 1km (Maccherone & Frazier, 2012). Figure 3.2 indicates the electromagnetic spectrum and the bands can be compared.

Only the first seven bands are indicated because the other bands have a resolution of 1km and are not used in fire investigations:

Band 1: (Red, 0.62-0.67µm, resolution: 250m)
Band 2: (NIR, 0.841-0.876µm, resolution: 250m)
Band 3: (Blue, 0.459-0.479µm, resolution: 500m)
Band 4: (Green, 0.545-0.565µm, resolution: 500m)
Band 5: (SWIR, 1.23-1.25µm, resolution: 500m)
Band 6: (SWIR, 1.628-1.652µm, resolution: 500m)
Band 7: (SWIR, 2.105-2.155µm, resolution: 500m)

(Lindsey & Herring, 2013)

3.6 Rectification of satellite imagery

All satellite data was rectified so that the different datasets could be compared (Mather, 2004) and used in a geographic information system (GIS). All data was also orthorectified. This is done with the aid of a digital elevation model (DEM). It was more crucial to rectify the imagery accurately in mountainous terrains. The accuracy of the position of the data is crucial because it can determine on which side of the fence the fire started. The accuracy is also important when change detection between images was done (Hoja *et al*, 2008) to determine the new fire scar. The orthorectification process was executed in the following way:

- Acquire a reference dataset of the area of interest. This data can be a topographic map or a dataset that is a well-registered representation of a portion of the earth and that can be used in a GIS.
- Obtain a digital elevation model (DEM) that covers the same area as the above-mentioned dataset.
- Gather ground control points from the reference dataset as well as the heights from the DEM and apply that to rectify the "new" dataset.
- The "new" dataset was processed and compared to the reference data to check for accuracy (Hoja *et al*, 2008). The formula to measure the accuracy error when doing an orthorectification is root mean square (Campbell & Wynne, 2008). The root mean

square of the accuracy must be less than a pixel in comparison to the new dataset (Hoja *et al*, 2008).

3.7 Determination of indices and the role they play in fire analysis

Indices are formulas that are used to calculate certain phenomena in remote sensing. The following indices are affected by a fire event: the normalized differential vegetation index (NDVI), the normalized burn ratio (NBR) and the normalized differential infrared index (NDII).

The first indice to be affected is the normalized differential vegetation index (NDVI) because fire has a devastating effect on vegetation. The NDVI is an equation involving the near infrared (NIR) and the red (RED) bands (Carla *et al*, 2011).

$$NDVI = (NIR - RED)/(NIR + RED)$$

The next indice that is affected by fire is the normalized burn ratio (NBR). The NBR consists out of NIR and short-wave infrared ($SWIR_{2.2}$) bands (Carla *et al*, 2011).

$$NBR = (NIR - SWIR_{2.2})/(NIR + SWIR_{2.2})$$

The last indice that is affected by a fire event is the normalized differential infrared index (NDII) which consists out of NIR and $SWIR_{1.6}$ bands (Carla *et al*, 2011).

$$NDII = (NIR - SWIR_{1.6})/(NIR + SWIR_{1.6})$$

Therefore, a burn ratio can be calculated by using band four (TM4 = NIR) and band seven (TM7 = $SWIR_{2.2}$) of Landsat. The use of vegetation indices like the normalized vegetation index (NDVI) and the two formulas for the burn indices are used. A normalized burn ratio (NBR) is the following:

$$NBR = (TM4 - TM7)/(TM4 + TM7)$$

(Brewer *et al*, 2005; Henry, 2008; Lentile *et al*, 2006; Key & Benson, 2006).

The burn index and the vegetation index are used to determine the total fire scar and the severity thereof (Key, 2005). The results of the different indices were added to the original bands of the sensor that was used. That increases the spectral depth and a supervised classification could be run to determine the fire scars more accurately.

The subtraction or differencing of the indices (that is the subtraction of the indice of the data after the fire from the indice of the data before the fire, i.e. change detection) became more popular in fire analysis and the calculation of the severity (Myoungsoo *et al*, 2011). The formula for the differencing NBR (dNBR) will be as follows:

$$dNBR = NBR_{prefire} - NBR_{postfire}$$

The change detection with the other indices was executed similarly (Carla *et al*, 2011). For multi-temporal usage, the two scenes are subtracted from each other, as well as the indices (Brewer *et al*, 2005; Key & Benson, 2006). Older burn scars are subtracted from the newer scar to put the emphasis on the newer. The multi-temporal usage of Landsat is often used to map the severity of wildfires in the case of Landsat 5. Because of the scan line corrector problem on Landsat 7, no change detection analysis can be done.

3.8 Classification of satellite images

"Digital image classification is the process of assigning pixels to classes." (Campbell & Wynne, 2011). Two main types of classifications are generally available, namely supervised and unsupervised classifications. Satellite imagery was classified to enhance the fire scar and to make it possible to vectorize the classified satellite image. The vectorized fire scar is then suitable for use in a geographic information system (GIS).

The medium resolution data was classified through supervised classification with the use of samples from the classes of known identity (Campbell &Wynne, 2011). To help determine the fire scar, the calculated indices were added to the original dataset. Those indices included the normalized vegetation index (NDVI), the normalized burn ratio (NBR) and the normalized differential infrared index (NDII). With supervised classification and change detection, old fire scars were separated from newer scars to eliminate the older scars through image subtraction.

During the supervised classifications the known samples, called training sites, were collected (Mather, 2004). The training sites were collected to guide the classification (Campbell & Wynne, 2011) in order to eliminate the fire scars. These sites were not only collected for the fire scars, but for other features also, to complete the information set. The identities of the other features are not important. Only in some instances is it important to have better accuracy on the other classes, for example when it needs to be determined what had been destroyed by the fire. Then there has to be differentiated between plantations, indigenous forests and grasslands. The final classification is then vectorized in a GIS (Hearnshaw & Unwin, 1994) to be able to calculate the area that had been destroyed by the fire.

The following method is used to do a supervised classification:

- Load data to be classified in a viewer.
- Draw training sites on areas of similar land cover, for example water, fire scars, agricultural fields, bare soil, etc.
- Run the supervised classification by using the parallelepiped method and evaluate.
- If not all the fire scars are classified, add more training sites for specific fire scars.

3.9 Vectorization of images

In a geographic information system (GIS), the vector data is manipulated. The vector data is made visible with a raster backdrop (Hearnshaw & Unwin, 1994). The vector data can consist out of points, for example when the information is obtained from AFIS and town locations.

The vector can consist out of polygons to indicate fire scars and farm boundaries. Sometimes, line data such as roads and power lines are also used.

The information obtained from AFIS was used in the GIS to keep track of the dates and times of the fires. The AFIS information was supported with the use of MODIS image data in the GIS. The vectorized area of the fire scar was calculated to determine the amount of hectares that had been destroyed. The vector areas of the old fire scars were subtracted from the new fire scars. By taking into account the shape of the fire scar, wind information and the AFIS data, the possible starting point was determined (Example figure 3.3). With the combinations of the fire scar vectors and the farm boundaries, the area per farm was calculated.

3.10 Ancillary Information

3.10.1 AFIS system

The Advanced Fire Information System (AFIS) monitors all active fires on a daily basis. The AFIS system is based on the Moderate Resolution Spectroradiometer (MODIS) data that is situated on board of the two satellites, Aqua and Terra. For the AFIS, the 1km short-wave infrared bands and the 1km thermal infrared bands of MODIS were used (Frost, 2012). AFIS also obtained information from Meteosat Second Generation (MSG), a geostationary weather satellite. MSG has a spatial resolution of 3km.

AFIS was developed by a remote sensing specialist of the CSIR in conjunction with the University of Maryland in the USA. This system was originally developed for use by Eskom. The people of Eskom wanted to know at any time of the day where a fire event took place so that they could extinguish it before the high voltage lines tripped, as a fire can cause a flashover (Frost, 2010). This system was developed to take care of that problem in the following way: AFIS detects the fire and then sends a warning cell phone message to the person in charge of a specific stretch of high voltage line. In that way a fire can be extinguished long before it changes into a wild, uncontrolled fire (Frost, 2012).

During a personal discussion with Philip Frost, the co-developer of the AFIS system from the CSIR, the following information was obtained. The AFIS system detected active flames from a fire in the mid-infrared range. The resolution of the mid-infrared bands and the thermal infrared bands that is used in the AFIS system is about 1km. The smallest flaming unit that can be detected is a 50m x 50m one. In the case of MSG, the smallest flaming unit is 500m x 500m.

3.10.2 The use of Google Earth for fire analysis

Google Earth was a great source of information because it uses high spatial resolution data. The spatial resolution of images used by Google Earth is about 0.6m. Google Earth imagery gave the high resolution information to determine a more defined starting point of the fire.

3.10.3 The use of weather conditions in fire analysis

Weather conditions play a major role in the spread of wildfires. Weather factors such as wind, temperature and humidity have a significant impact on a fire (Steensland *et al*, 2005). Humidity and temperature affect the starting point and the behaviour of the fire. Wind plays a crucial role in the spread of a fire. Wind makes a fire burn in an ellipsoidal pattern (figure 3.3), and the shape of the ellipsoid depends on the strength of the wind (Finney, 1998; Steensland *et al*, 2005). The image in figure 3.3 is a typical example of a fire that occurred during a strong wind.

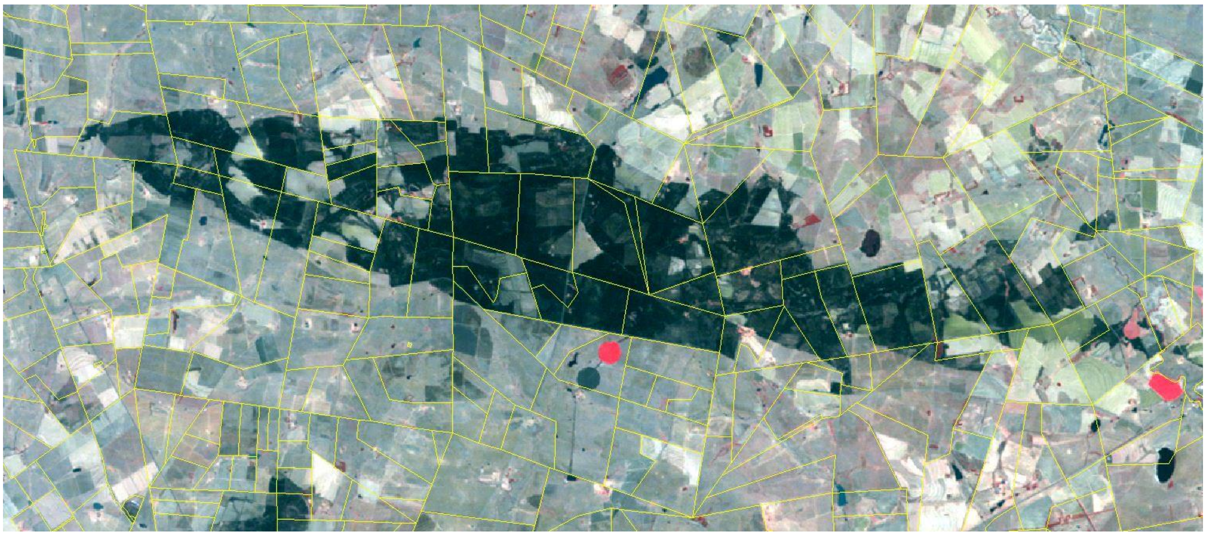

Figure 3.3: A fire scar originated by a strong wind (Vorster, 2011)

The wind strength is measured by using the Beaufort Scales. The Beaufort Scales determine wind speed and was developed in 1806 by Sir Francis Beaufort (Halsey *et al*, 1971).

Force	**Speed**			**Name**	**Conditions at sea**	**Conditions on land**
	knots	**km/h**	**mi/h**			
0	< 1	< 2	< 1	Calm	Sea like a mirror	Smoke rises vertically
1	1-3	1-5	1-4	Light air	Ripples only	Smoke drifts and leaves rustle
2	4-6	6-11	5-7	Light breeze	Small wavelets (0.2m) Crests have a glassy appearance	Wind felt on face
3	7-10	12-19	8-11	Gentle breeze	Large wavelets (0.6m) Crests begin to break	Flags extended, leaves move
4	11-16	20-29	12-18	Moderate breeze	Small waves (1m), some whitecaps	Dust and small branches move
5	17-21	30-39	19-24	Fresh breeze	Moderate waves (1.8m), many whitecaps	Small trees begin to sway
6	22-27	40-50	25-31	Strong breeze	Large waves (3m), probably some spray	Large branches move, wires whistle,

						umbrellas are difficult to control
7	28-33	51-61	32-38	Near gale	Mounting sea (4m) with foam blown in streaks downwind	Whole trees in motion, difficulty walking
8	34-40	62-74	39-46	Gale	Moderately high waves (5.5m), crests break into spindrift	Difficult to walk against wind. Twigs and small branches blown off trees
9	41-47	76-87	47-54	Strong gale	High waves (7m), dense foam, visibility affected	Minor structural damage may occur (shingles blown off roofs)
10	48-55	88-102	55-63	Storm	Very high waves (9m), heavy sea roll, visibility impaired. Surface generally white	Trees uprooted, structural damage likely
11	56-63	103-118	64-73	Violent storm	Exceptionally high waves (11m), visibility poor	Widespread damage to structures
12	64+	119+	74+	Hurricane	14m waves, air filled with foam and spray, visibility bad	Severe structural damage to buildings, wide spread devastation

Table 3.1: Beaufort Scales for the interpretation of wind speed (Rowlett, 2001)

3.10.4. Fieldwork for fire analysis

Fieldwork for fire investigations does not have the same value after three years as it would have shortly after the fire event because after three years, most of the vegetation had grown back. A dispute about a fire occurred about three years after the event. A few features can be seen after three years that can be of value. One of the valuable features is to confirm the wind direction. One way to determine wind direction is to look at fence poles. A feature that can determine the wind direction is the charcoal side of a pole. If the wind blows from east to west, the western side of the pole has more charcoal than the eastern side (Steensland *et al*, 2005). By using this method, one can assume that there was no fire after the one under investigation.

3.10.5. Calculation of terrain and different portions

Finally, the total area of the fire scar was calculated in a GIS and the calculation unit was in hectares. With the farm boundaries in mind, the fire scar was divided into the portions per farm that had been destroyed. This calculation was used in the UTM projection and the areas of the farm portions were calculated in hectares.

Chapter 4: Analysis

4.1. Introduction

For fire investigations, the starting time, the starting point and the spread of the fire is very important. The total area that was destroyed is important to calculate the loss suffered through the fire. This chapter is based on case studies to illustrate the above-mentioned factors. The first two case studies demonstrated the normal application of the method while the third case study demonstrated a more extensive analysis.

The first case study involved a forest fire near Sabie in Mpumalanga. This case study started in dry conditions with strong, changing winds. The Sabie fire burned in 2007 and was one of three fires that destroyed about 9% of the plantations in Mpumalanga. For this case study, only one of the three fires in the Sabie region was analysed.

The second case study involved a grass veld fire near Bethal in Mpumalanga. This case study started in dry conditions with a strong wind. This fire burned in 2008 and burned rapidly. It was a typical grass fire.

The third case study involved a combination of fires near Carletonville in the North West Province. These fires burned in 2011. It was a combination of at least three separate fires that burned into each other and caused a large fire scar. This fire scar had to be dissected to determine which fire was responsible for which destroyed area.

4.2. Case Study 1 – Mpumalanga Fire

4.2.1. Description of the terrain

The Mpumalanga Escarpment lies on the eastern side of the country. The escarpment falls in an elongation of the Drakensberg mountain range towards the north. The terrain consists out of high mountains and hilly terrain (figure 4.1). The escarpment is the barrier between the eastern Lowveld with the Kruger Park and the western Highveld. Commercial forestry is the main farming activity in this area. Mainly pine and eucalyptus plantations are found here. The eastern parts of the escarpment consist mostly out of tropical farms which include banana, citrus and mango orchards.

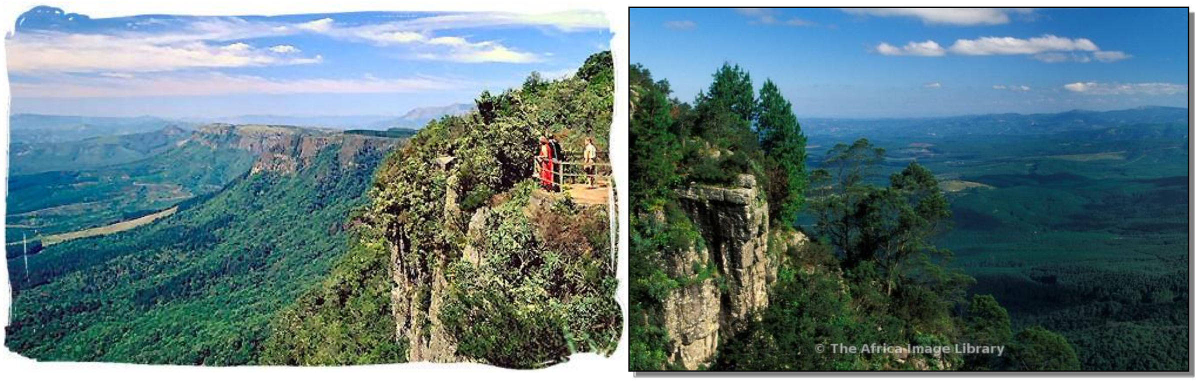

Figure 4.1: Two images of the escarpment

Figure 4.2 indicates where Sabie is situated in the Republic of South Africa. The year 2007 was a dry year and the study was conducted just after the middle of winter. Strong westerly winds blew during this time (SA Forestry Magazine, 2012). On 27 July 2007, three large wildfires destroyed about 9.5% of the forest plantations of Mpumalanga (Forsyth *et al*, 2010). These three wildfires occurred east of Lydenburg in the vicinity of Graskop and Sabie (figure 4.2 and figure 4.3) on the escarpment. Only the Sabie fire is discussed in this study. Figure 4.3 shows a Landsat image of the area with the Sabie region on 15 May 2007, before the fire, in true colour with band combination 3, 2, 1 indicated by red, green and blue. Most of the green areas are plantations. In the top left corner of the image are grasslands.

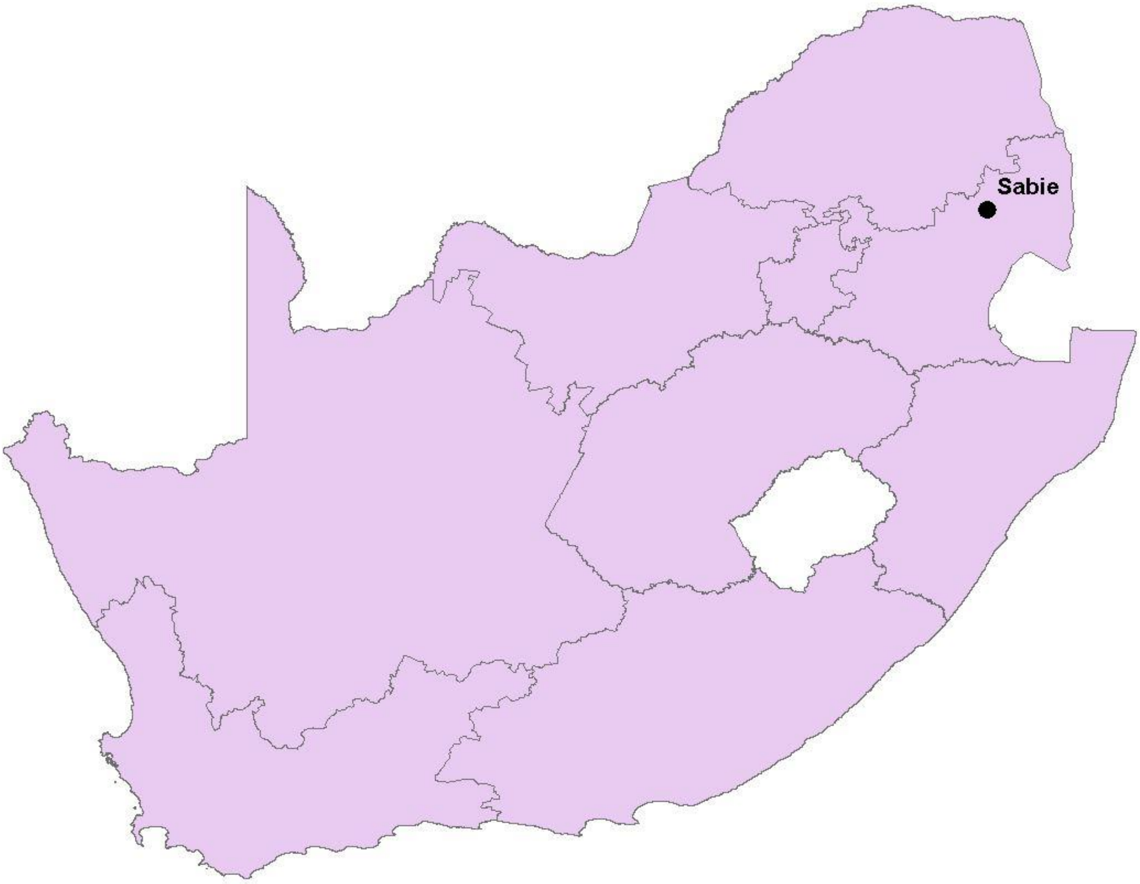

Figure 4.2: Map of the town of Sabie where the study area was

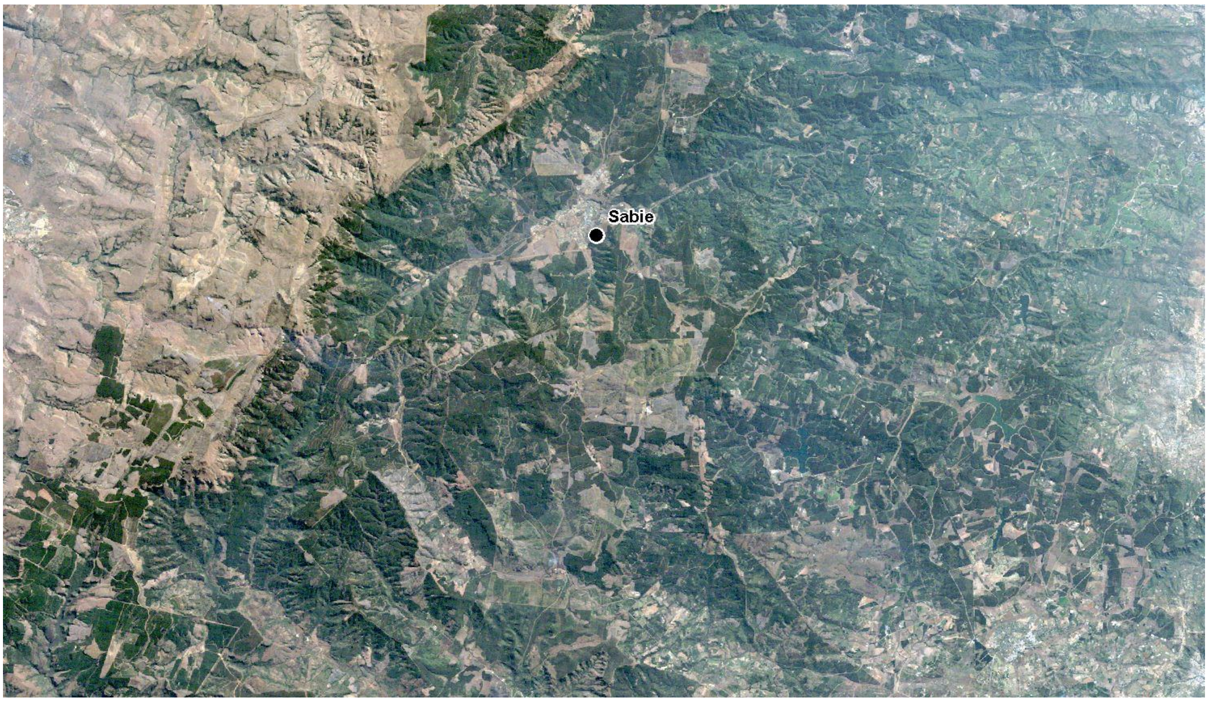

Figure 4.3: True colour Landsat image of 15 May 2007 of the region with Sabie

4.2.2. Data used

Landsat 5 data and MODIS data were available for this study. The Landsat 5 data of 15 May 2007 and 18 August 2007 were used, one image before the fire and the other image after the fire. The MODIS data was used as a time series to keep track of the fire. From AFIS, the information from MODIS and MSG (Meteosat Second Generation, with a spatial resolution of 3km), the spread of the fire was determined.

4.2.3. Rectification and application of indices

The data was rectified to the UTM projection. The Landsat data was orthorectified with the aid of a digital elevation model and a reference dataset. To enhance the burnt area, the NDVI and fire indices were calculated and added to the original dataset. In the following three figures, the different indices calculated from the Landsat data of 18 August 2007 are shown. In all these indices, the normalized differential vegetation index (NDVI) in figure 4.4, the normalized burn ratio (NBR) in figure 4.5 and the normalized differential infrared index (NDII) in figure 4.6, the forested areas, and subtropical farming activities are in bright white because of the chlorophyll radiation. On the far left side of the images there are grasslands. The new burn scar is in the centre of all the images. With the NBR, the grass could be differentiated from the old burn scars. None of the indices is discussed. Their only purpose is to enhance the fire scar in order to aid the supervised classification.

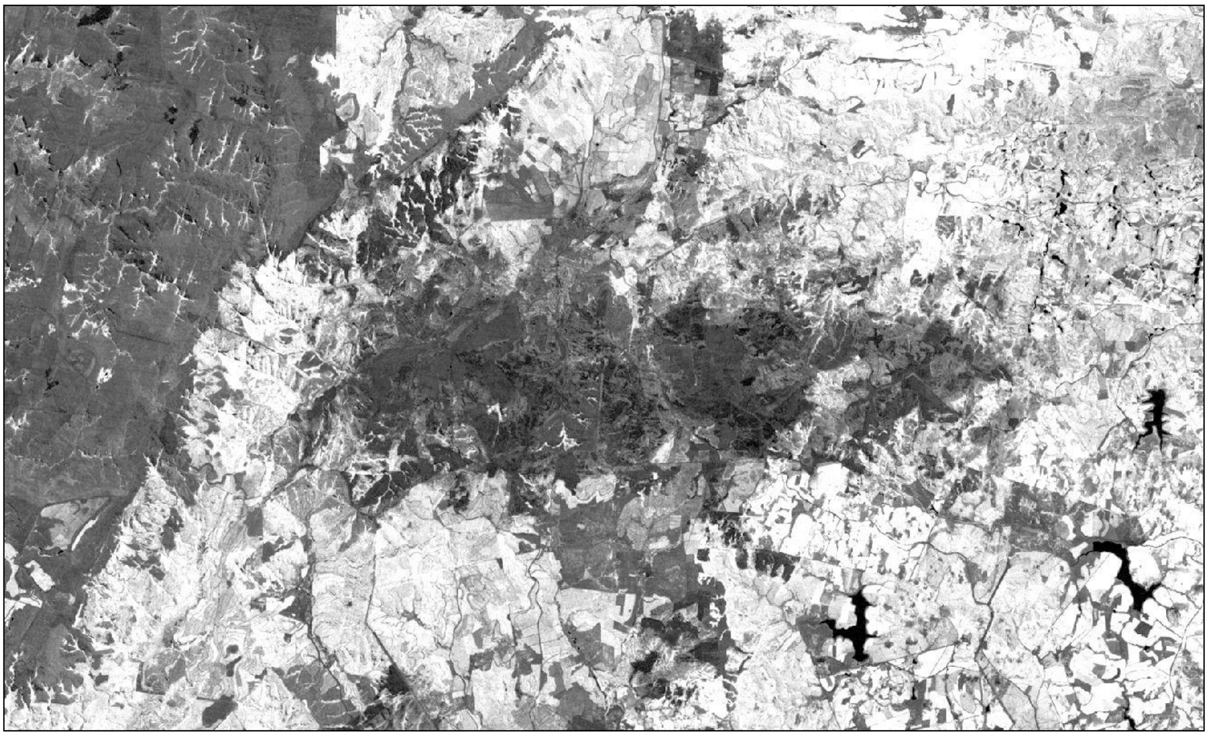

Figure 4.4: NDVI on the Landsat data of 18 August 2007

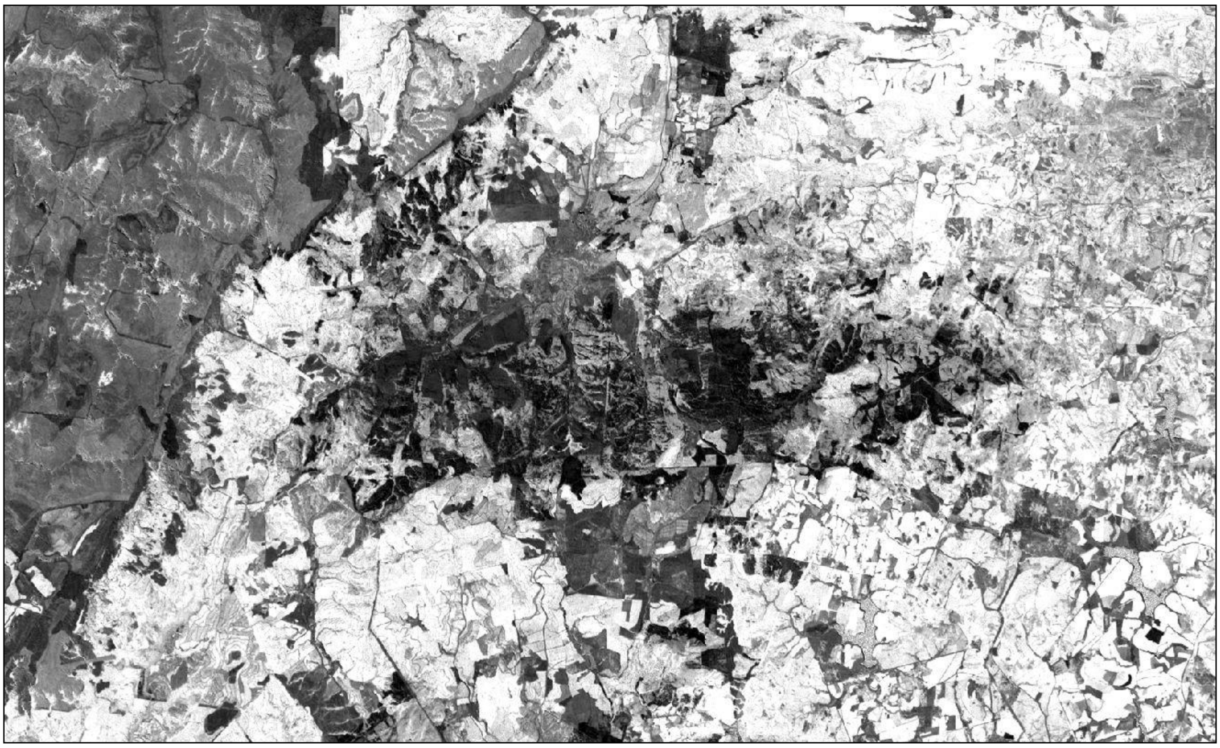

Figure 4.5: NBR on the Landsat data of 18 August 2007

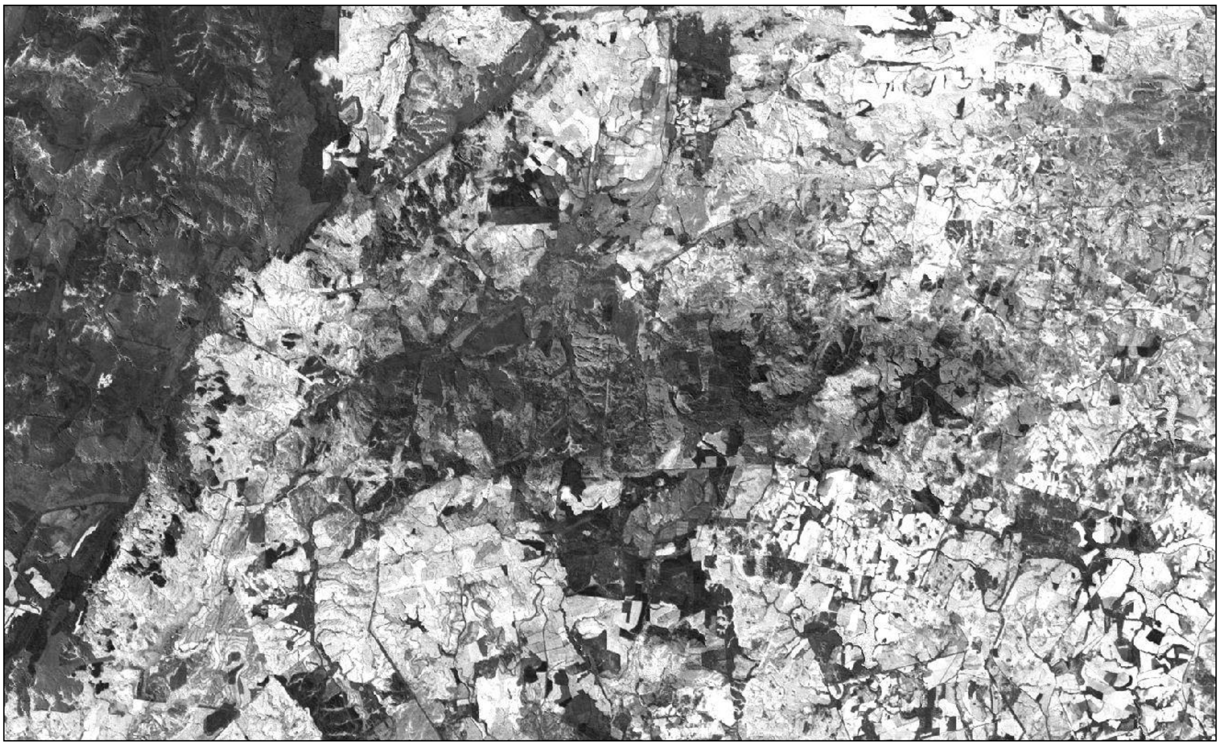

Figure 4.6: NDII on the Landsat of 18 August 2007

4.2.4. Classification

The calculated indices (NDVI, NBR and NVII) were added to the original Landsat dataset and then a supervised classification was executed with the aid of training sites. All the red areas in figure 4.7 indicate the fire scars. The green colours represent the high chlorophyll radiation, the blue indicates water, the tan indicates grassland, and the beige indicates bare soil in figure 4.7. The older data, Landsat image of 15 May 2007, was classified in the same way and subtracted from the newer image, the classification of the Landsat image of 18 August 2007. The reason for doing this is to eliminate the old fire scars from the newly burnt areas.

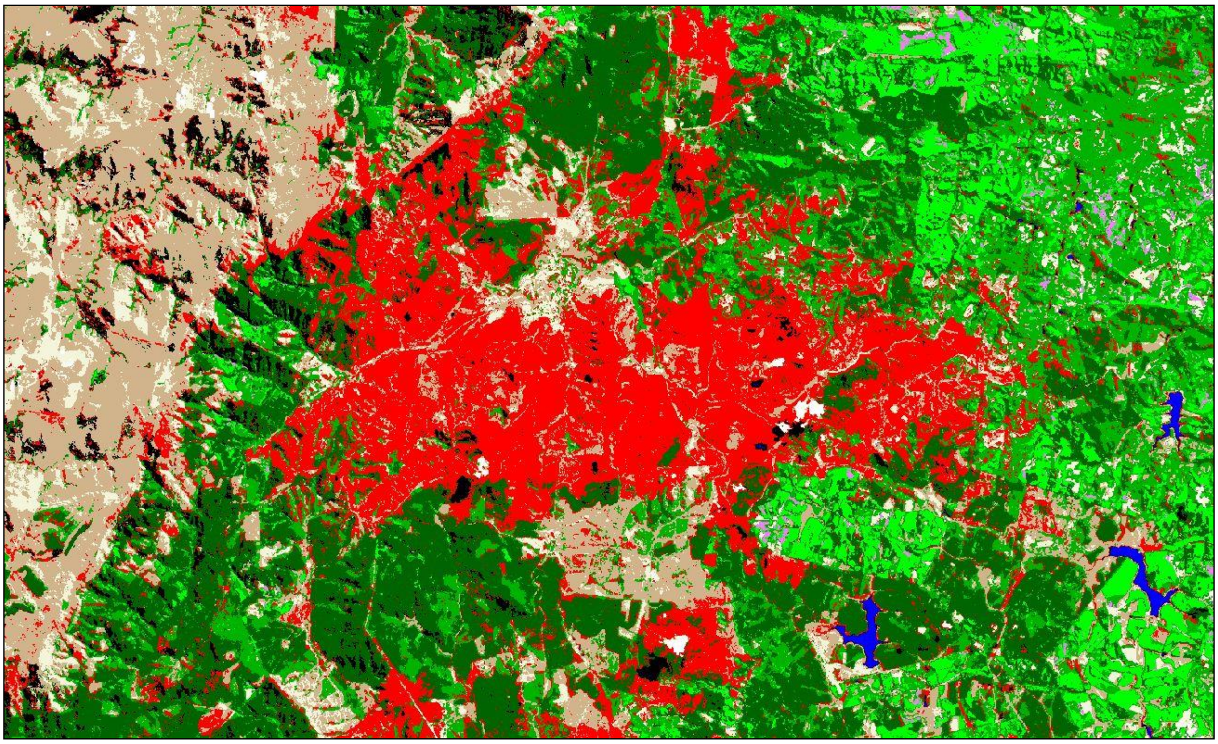

Figure 4.7: Supervised classification of the Landsat of 18 August 2007

4.2.5. The spread of the fire calculated from AFIS

The MSG (Meteosat Second Generation) satellite is the weather satellite that detects weather information in Africa and Europe. It has a resolution of about 3km. This satellite is a geostationary satellite and is situated about 36 000km from the earth. The MSG satellite takes an image of the earth every fifteen minutes, which makes it ideal to track fires despite, the low resolution. Table 4.1 shows an example or part of the data from the MSG satellite that was used in AFIS. International time (Greenwich Mean Time) was used. To convert that to local time in South Africa, two hours had to be added.

LAT	LON	TEMP	N1	N2	DAY_MONTH_	TIME	SATELLITE	CONFIDENC
-25.311	30.782	312.000	0	0	27/07/2007	1315	M	0
-24.891	30.757	306.500	0	0	27/07/2007	1845	M	0
-24.922	30.729	321.500	0	0	27/07/2007	1845	M	0
-24.923	30.768	330.000	0	0	27/07/2007	1845	M	0
-24.925	30.806	330.000	0	0	27/07/2007	1845	M	0
-24.927	30.845	320.500	0	0	27/07/2007	1845	M	0
-24.954	30.740	330.000	0	0	27/07/2007	1845	M	0
-24.956	30.779	322.000	0	0	27/07/2007	1845	M	0
-24.958	30.817	321.000	0	0	27/07/2007	1845	M	0
-24.959	30.856	315.500	0	0	27/07/2007	1845	M	0
-24.892	30.796	306.500	0	0	27/07/2007	1900	M	0
-24.925	30.806	330.000	0	0	27/07/2007	1900	M	0
-24.927	30.845	326.500	0	0	27/07/2007	1900	M	0
-24.953	30.702	330.000	0	0	27/07/2007	1900	M	0
-24.954	30.740	312.500	0	0	27/07/2007	1900	M	0
-24.956	30.779	323.500	0	0	27/07/2007	1900	M	0
-24.958	30.817	328.000	0	0	27/07/2007	1900	M	0

Table 4.1: An example of the AFIS with the MSG data

For AFIS to detect a fire from the MSG, the fire must be at least 500m in diameter (Frost, 2012). Figure 4.8 shows the first few hours of the devastating fire that burned in the Sabie region on 27 June 2007. To visualize a table in a geographical way, triangles are used to indicate the tracking of the fire.

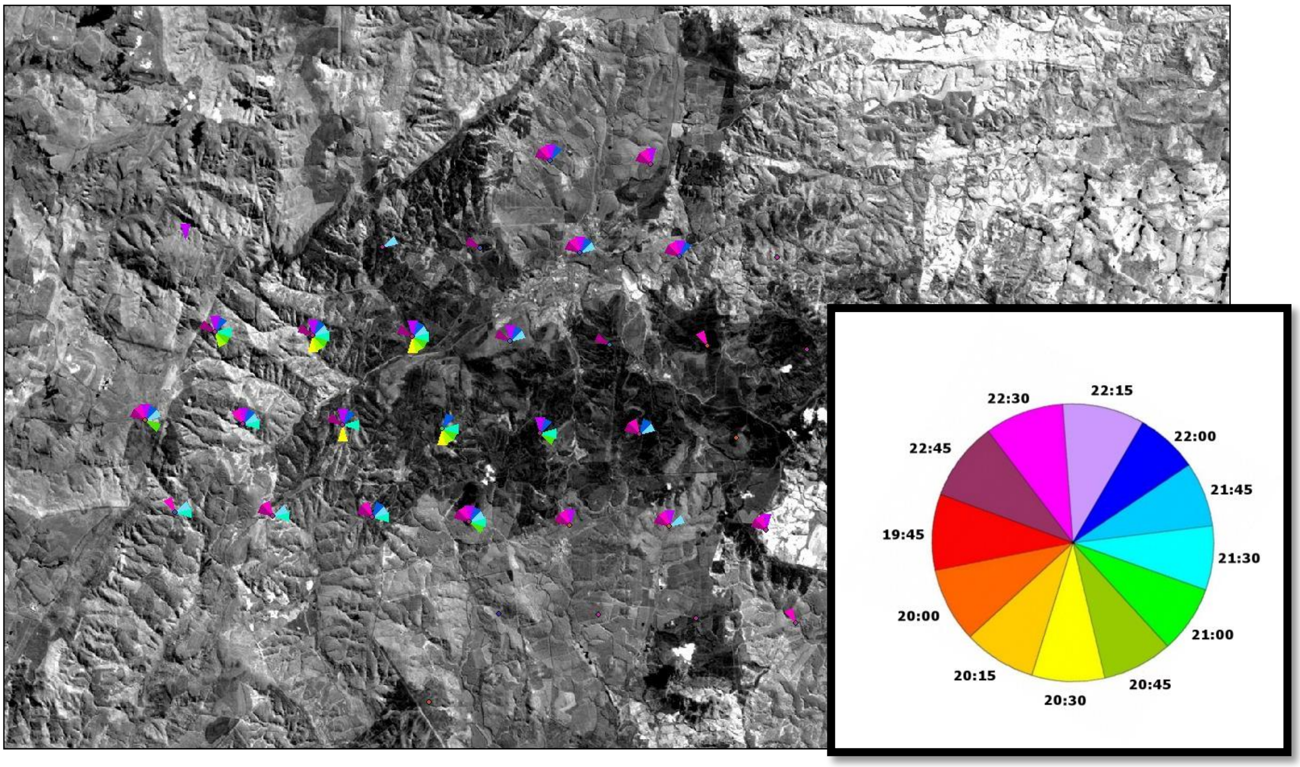

Figure 4.8: MSG representation of the first few hours of the fire. The backdrop is from the Landsat of 18 August 2007. (The legend in the pie diagram indicates the progress of the fire in local time format.)

The yellow triangles indicate the area where the fire had first been detected, at 20:30. The progress of the fire is indicated anti-clockwise on the pie diagram. The second time the fire was detected, at 20:45, is indicated by the green triangle.

The other sensor that is supported by AFIS is the MODIS sensor that has a spatial resolution of 250m to 1 000m. From AFIS, the MODIS sensor could detect a fire as small as 50m in diameter. The actual fire was detected at the spatial resolution of 1km. Figure 4.9 portrays the information from the MODIS data in AFIS detected at 01:20 on 28 June 2007 and it is indicated by the red dots. The whole area around Sabie was on fire when the MODIS sensor detected it for the first time, just after midnight. Actually, two fires burned, the upper eight dots indicate a second fire.

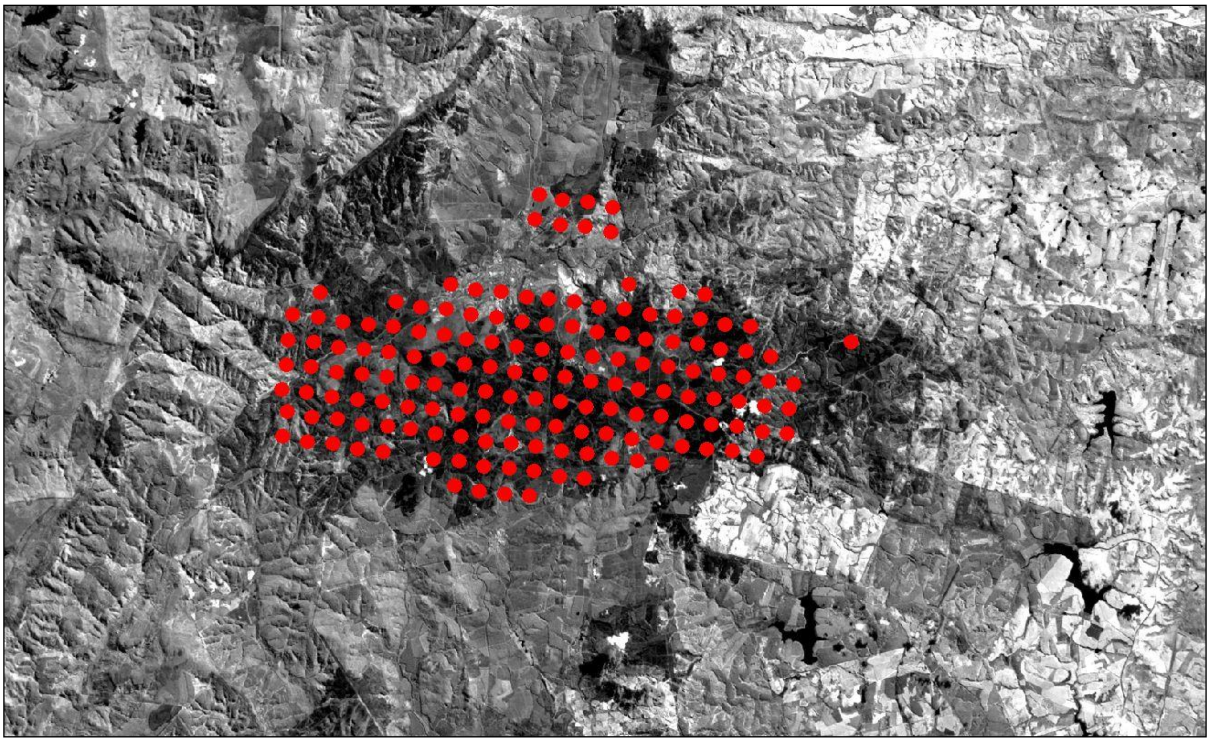

Figure 4.9: MODIS information of 01:20 local time on 28 June 2007 with the Landsat of 18 August 2007 as backdrop

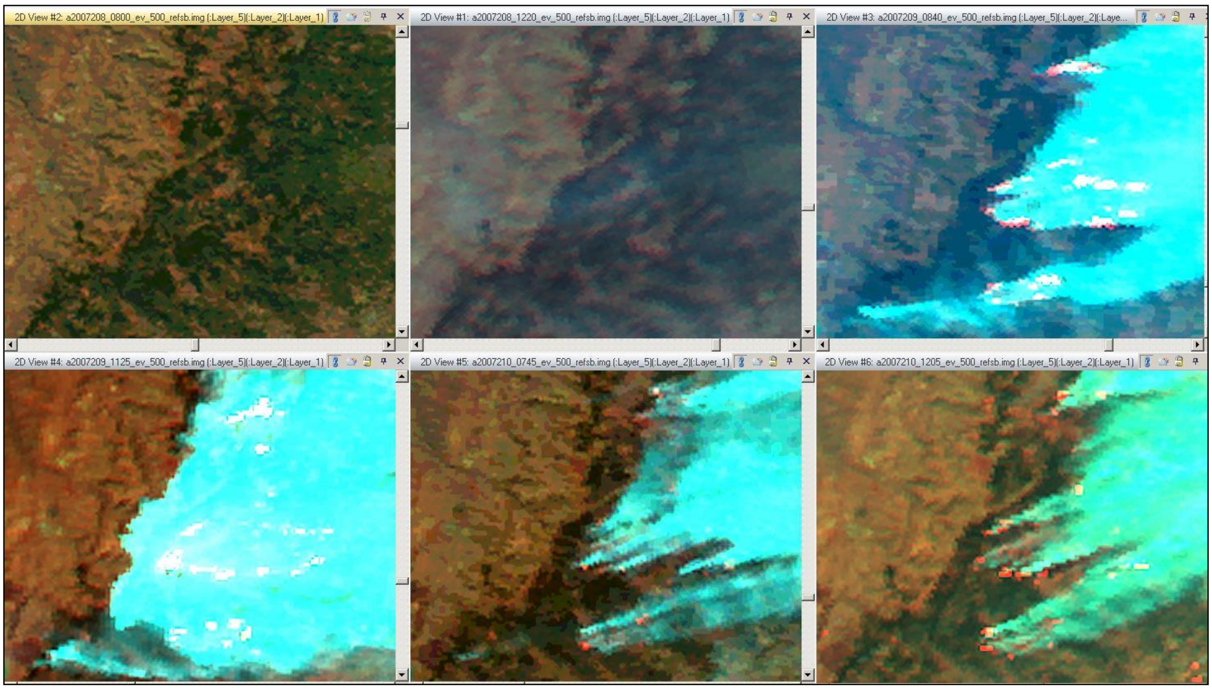

Figure 4.10: MODIS time series of the first three days of the fire – From 27 July 2007 to 29 July 2007

Figure 4.10 portrays a time series of MODIS data from 27 July 2007 to 29 July 2007. In the morning (at 10:00) on 27 July 2007, no fire was visible, not even smoke. At 14:20 on 27 July 2007, smoke was visible. The fire started on the evening of 27 July 2007, before 20:30. Satellite MSG detected the fire for the first time at 20:30, and for MSG to detect a fire, it must be at least 500m in diameter. The next day, 28 July 2007, the whole area was on fire and it was detected by MODIS at 10:40. With the next three overpasses of the MODIS sensor, fire was burning over a large area.

4.2.6. Vectorization of the area and area determination

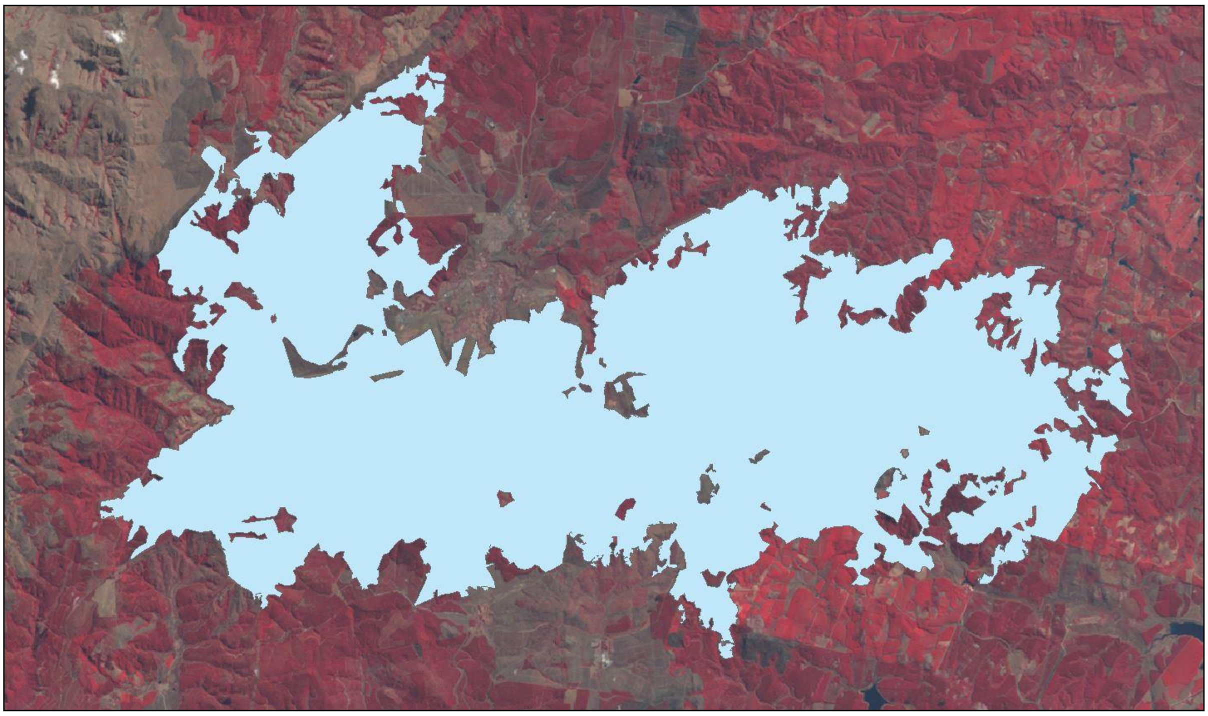

Figure 4.11: This is a vectorized fire scar with the Landsat of 18 August 2007 as backdrop

Figure 4.11 shows a vector of the fire scar derived from the classified image in figure 4.7. The vector data is draped over the Landsat image of 18 August 2007 with band combination 4, 3, 2 indicated by red, green and blue. In this image, the red indicates high chlorophyll vegetation, the green-yellow indicates grass, and the black areas indicate burn scars. All classified data was vectorized and the vectors of the old fire scars were subtracted. The new fire scar was edited to determine the whole fire scar of the burnt area because the vectorization sometimes does not include all the burnt areas. The area was then calculated to determine the destroyed area. The total area that was destroyed during this wildfire was approximately 27 913.9 hectares.

4.2.7. Determination of the starting point

Another very important factor in fire scar analysis is determining the area where the fire started. Who was responsible? In figure 4.12 is the Landsat image of 18 August 2007 with the mapped fire scar and the zoom-in of the area where the fire probably started. The Landsat image was loaded with the band combination 7, 4, 1 indicated by red, green and blue. The high chlorophyll vegetation showed up as green. The burn scar had the red/brown colour. The zoom-in picture in the top right hand corner in figure 4.12 indicates the area where the fire probably started on 27 July 2007.

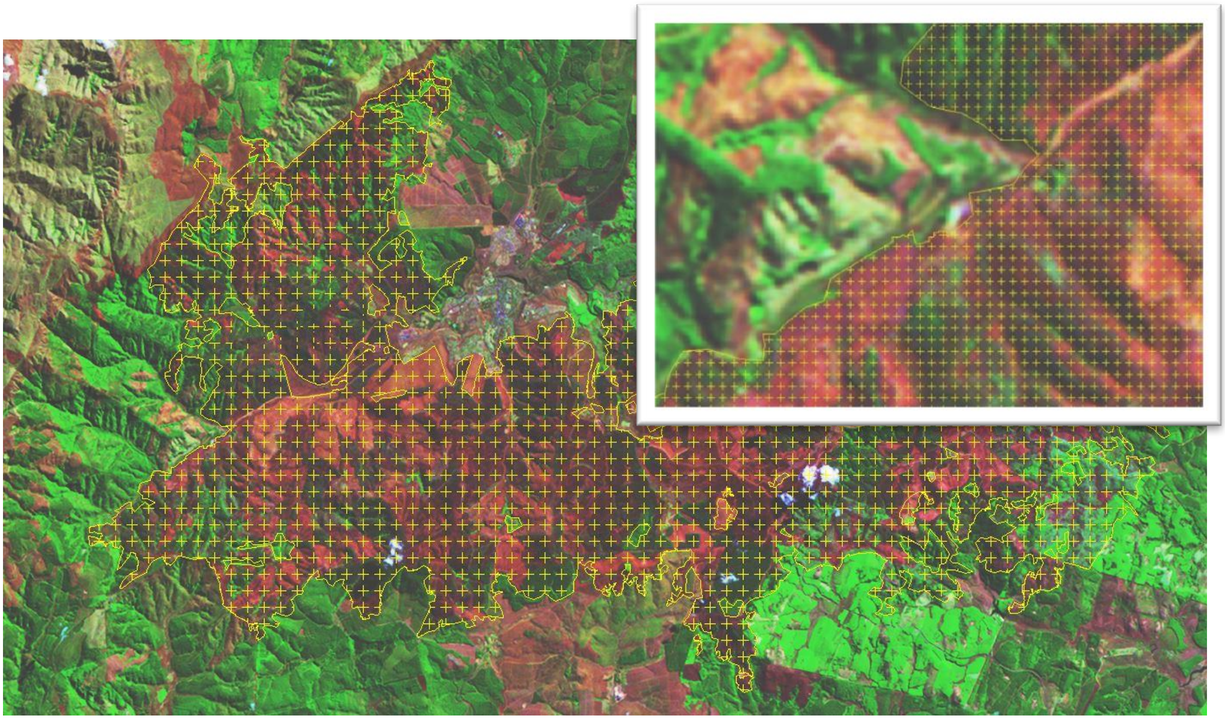

Figure 4.12: Landsat image of 18 August 2007 with the mapped fire scar and area of probable starting point (in zoom-in picture)

4.2.8. Additional information datasets

The National Land Cover dataset of 2000 (NLC2000) was used to identify the vegetation that was destroyed during the Sabie fire. The NLC2000 was derived from Landsat data through a consortium of companies (Van den Berg *et al*, 2008). The NLC2000 was developed to identify the different land cover vegetation throughout the country in the Republic of South Africa. Figure 4.13 is a cutout from the NLC2000 and it was combined with the Sabie fire scar to indicate what type of vegetation was destroyed during the fire event. The fire event took place in 2007 (seven years after the NLC2000 project), which means that the forest clear felled areas had relative young trees on them and the other plantation areas had older trees on them. From all the classes, more emphasis was put on areas with plantations.

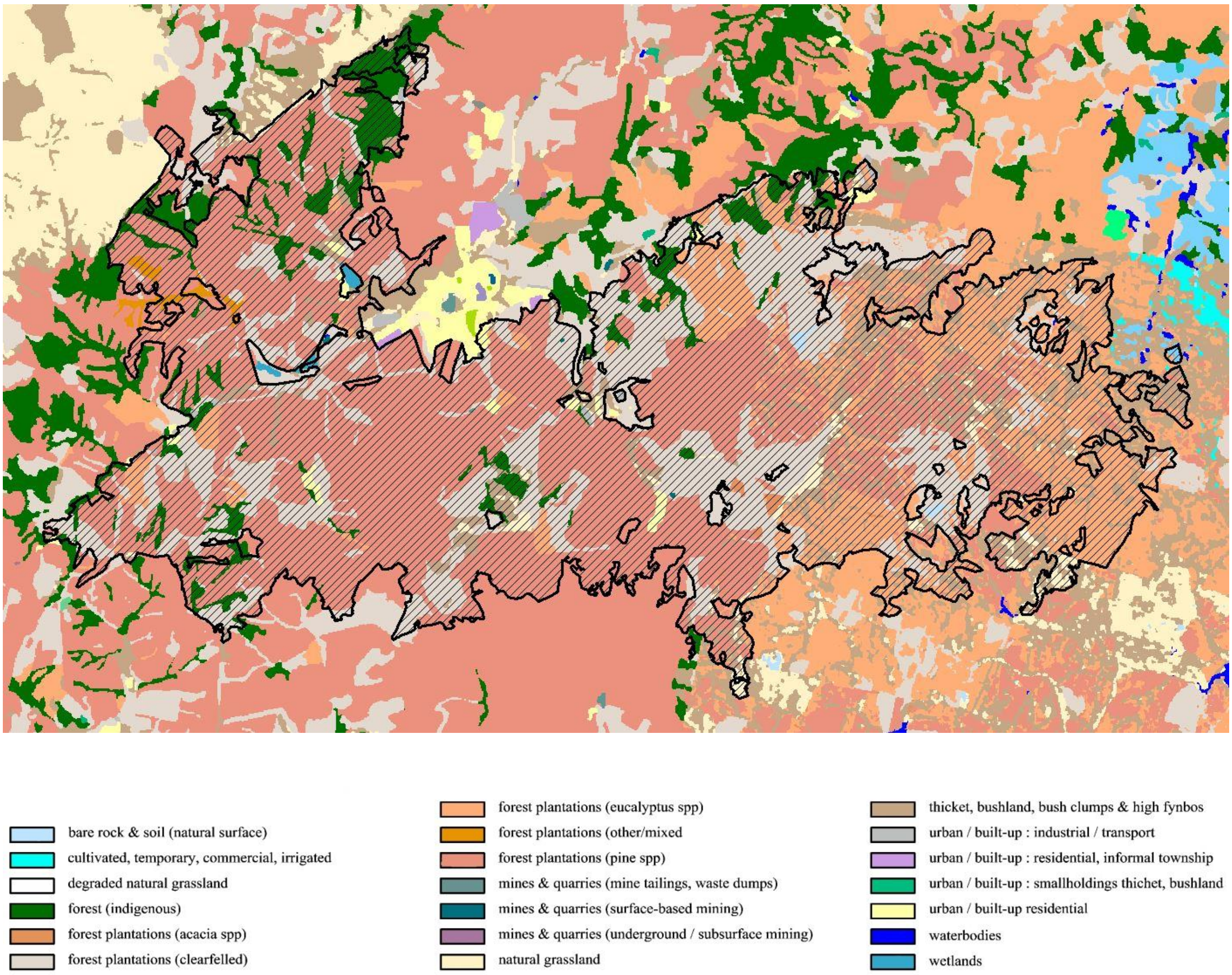

Figure 4.13: The fire scar of the Sabie area on top of the NLC2000

Figure 4.14 gives an indication of the plantations that were destroyed during the fire, based on the NLC2000. Only two types of plantations were extracted from the NLC2000. The dark green indicates all the pine plantations and the green the eucalyptus plantations. From that information, the total plantation areas could be calculated. The total area of pine planation was approximately 12 797.5 hectares and the eucalyptus 4 166.3 hectares. Areas that were clear felled in NLC2000 were not considered for the 2007 calculations because it was not known what was growing there when the wildfires broke out.

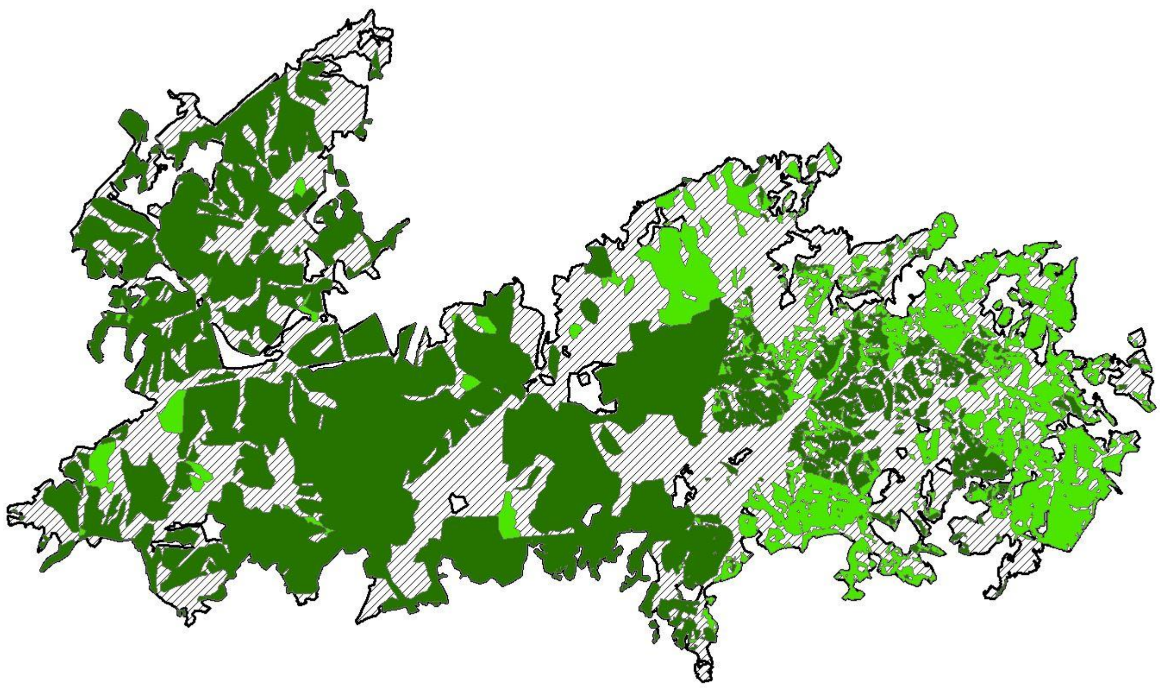

Figure 4.14: Plantations destroyed during the fire event

4.3. Case Study 2 – Fire near Bethal

4.3.1. Description of the terrain

The town of Bethal (figure 4.15) lies on the Highveld in Mpumalanga at an average height of 1 649 metres above sea level. The Highveld has hot summers with summer rainfall and very cold winters with frost. In winter, there is very little or no rainfall in this area. The main farming activities are maize, potatoes and sunflower crops (Saayman, 2010) and cattle on the grassy areas. It is surrounded by power stations and coal mines (Saayman, 2010). The Highveld consists mostly out of grassland. The grass, which grew during the summer months, died off completely in winter due to frost. Every year, wildfires ravage through this area. Strong westerly winds just after midwinter are common in this area.

Devastating fires, such as those in 2008, are also not out of the ordinary. On 30 August 2008, a fire started on the farm Rietfontein, southeast of Bethal, and burned eastwards due to a strong westerly wind.

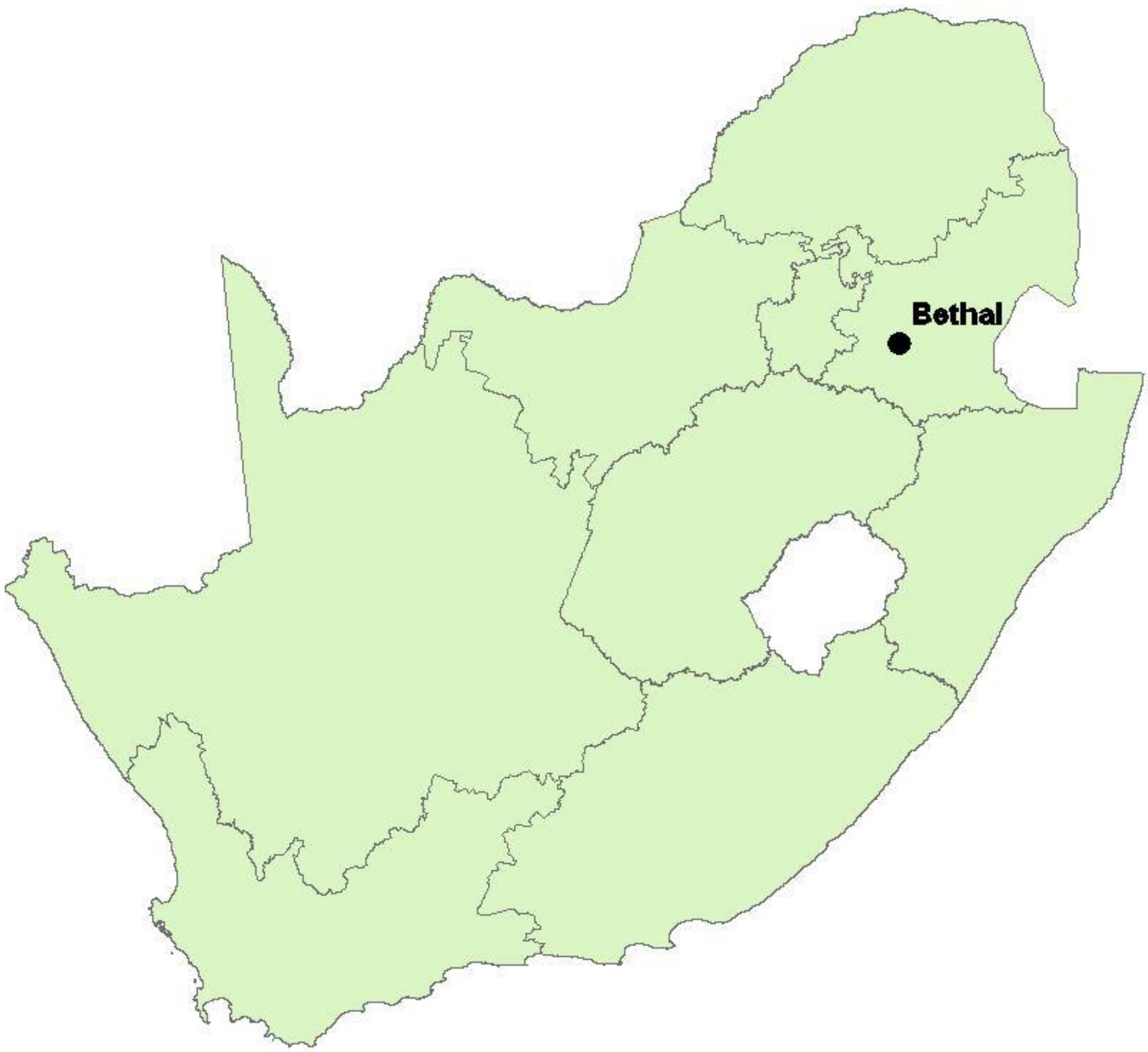

Figure 4.15: The town of Bethal, close to the study area

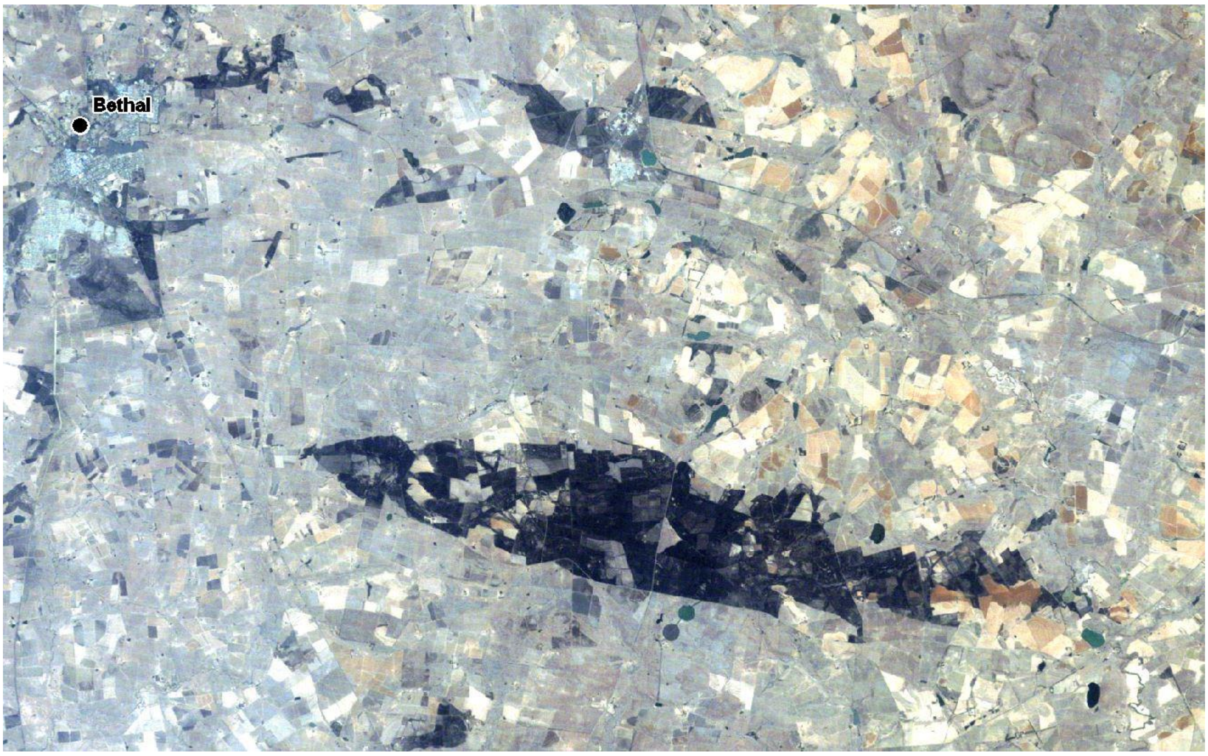

Figure 4.16: A true colour image of Landsat of 4 September 2008. The town of Bethal is visible on the top left hand corner.

4.3.2. The data used

The data that was used in this study was obtained from Landsat and MODIS. The Landsat 5 data of 4 September 2008 (figure 4.16) was used to analyze this fire event. Only one Landsat image was available in the data archive, the image after the fire of 4 September 2008. MODIS data with a resolution of 250m was obtained before and after the fire event. No data was obtained from AFIS because the fire event took place between the two overpasses of the MODIS sensor. The vector data used for this fire was the farms layer and the roads layer obtained from the Surveyor General.

4.3.3. Rectification and application indices

The Landsat data, obtained from SANSA, was orthorectified with the aid of an elevation model and reference data derived from SPOT 5 data. The elevation data with a resolution of 20m was derived from the 1:50 000 topographic maps of South Africa. The Landsat data was rectified to the UTM, Zone 35 projection.

Figure 4.17 shows an image of Landsat 5 on 5 September 2008 with a band combination 7, 4, 1 indicated by red, green and blue. The fire had a devastating effect on the vegetation, thus band 4 had no reflection and showed up as the red/purple area. The green areas are irrigated areas with crop fields. The pinkish colours indicate grass veld. The white areas indicate bare soil. The red lines indicate the road networks and the yellow lines the farm boundaries with a few names.

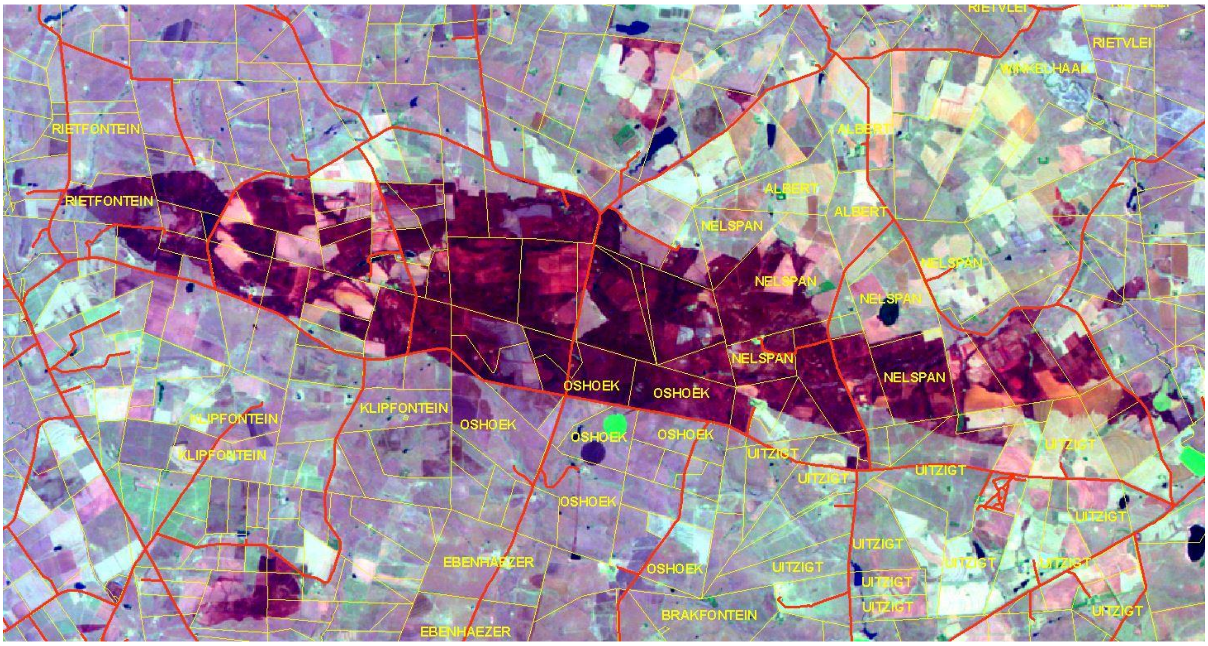

Figure 4.17: A Landsat image of 4 September 2008 of the burnt area with the farm boundaries and roads

After the Landsat rectification, the NDVI and the fire indices were calculated and added to the original Landsat to prepare it for classification. Figure 4.18 indicates the combination of the indices. The normalized burn ratio (NBR) is red, the normalized differential infrared index (NDII) is green, and the normalized vegetation index (NDVI) is blue. The two burn ratios show some radiation on the burn scar (the greens and yellows). Very little radiation came from the blue because the vegetation had been destroyed.

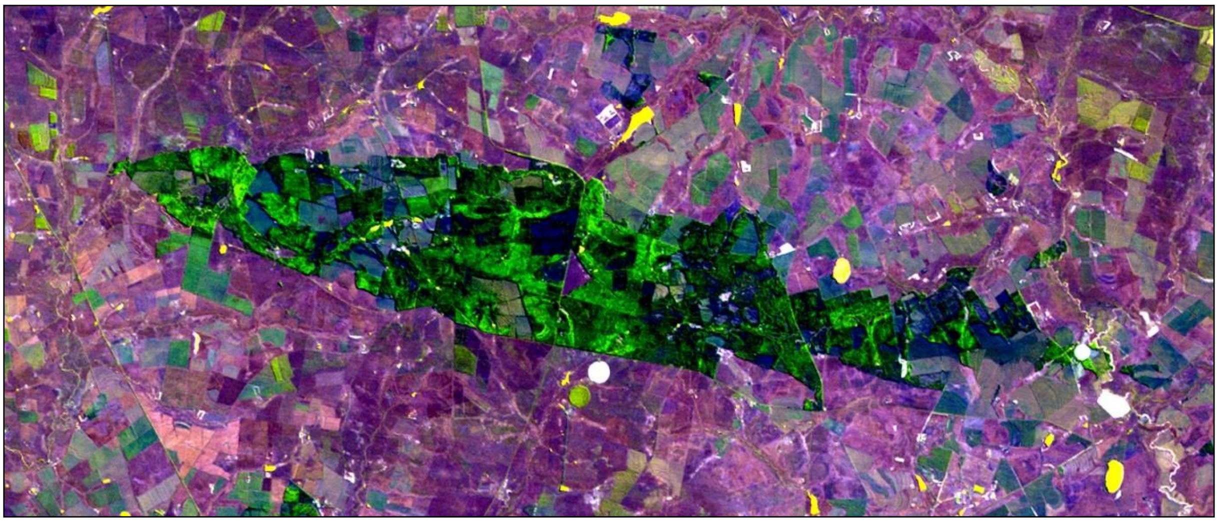

Figure 4.18: The fire scar with the combinations of the indices NBR, NDII, NDVI in red, green and blue

The indices were added to the original Landsat dataset and a supervised classification was run to eliminate the fire scar from the Landsat image.

4.3.4. Classification

The Landsat data was classified by using supervised classification. The training areas of the classes were concentrated only on the fire scars and the signatures of all the other classes were ignored (figure 4.19) and coloured in blue. Red indicates all burnt areas.

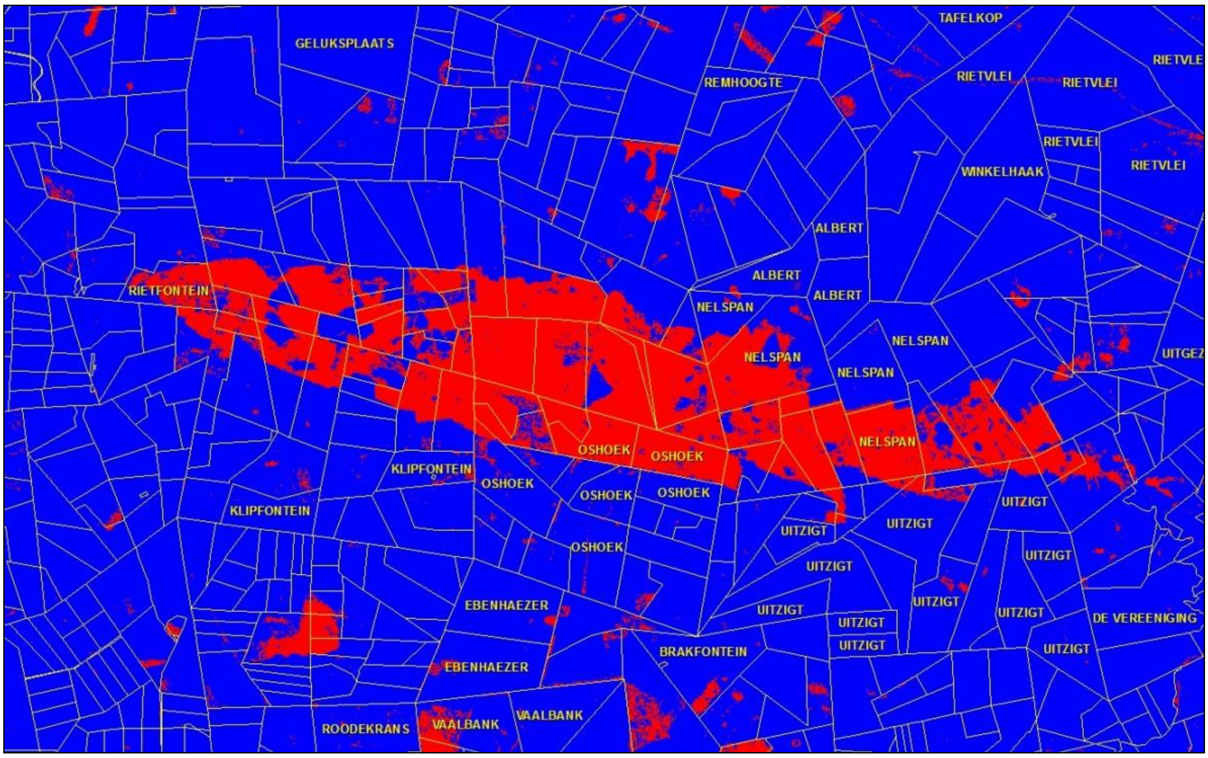

Figure 4.19: Supervised classification of the Landsat to determine the fire scar

4.3.5. The spread of the fire calculated from AFIS

The following three images of MODIS indicated the progress of the fire. The fire started after 10:00 on 30 August 2008 as no fire or fire scar was visible on 30 August 2008 at 10:00 (figure 4.20). At 14:20 on 30 August 2008, a fire is visible on the right hand side of the starting point, which means that the fire started before 14:20 (figure 4.21). The smoke above the green line of the fire scar indicates the direction of the wind and the fact that it is a narrow plume indicates that a strong wind blew. Figure 4.22 indicates the final fire scar on 31 August 2008 at 10:40.

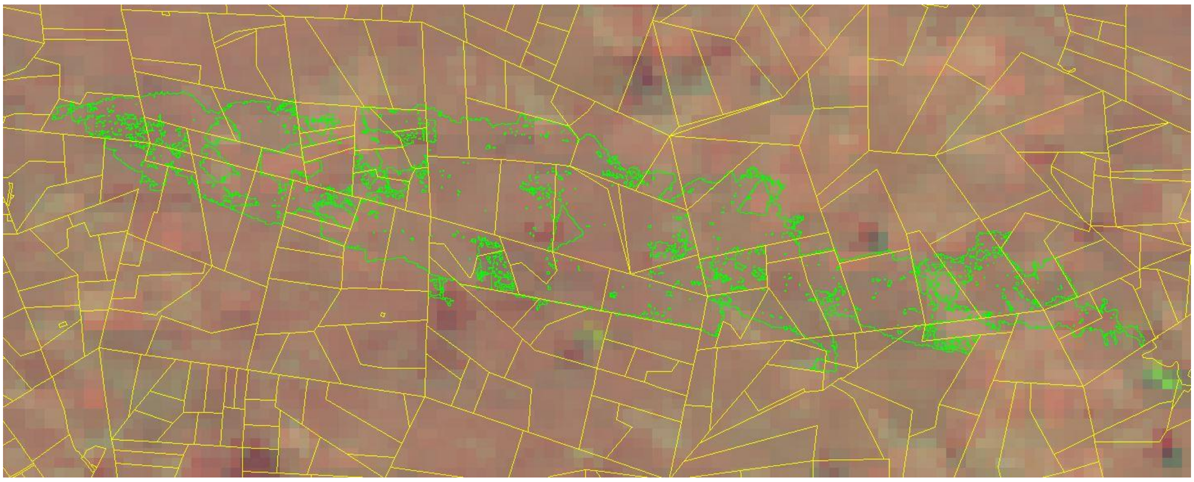

Figure 4.20: MODIS imagery of 30 August 2008 at 10:00. The yellow lines indicate the farm boundaries and the green lines indicate the final fire scar.

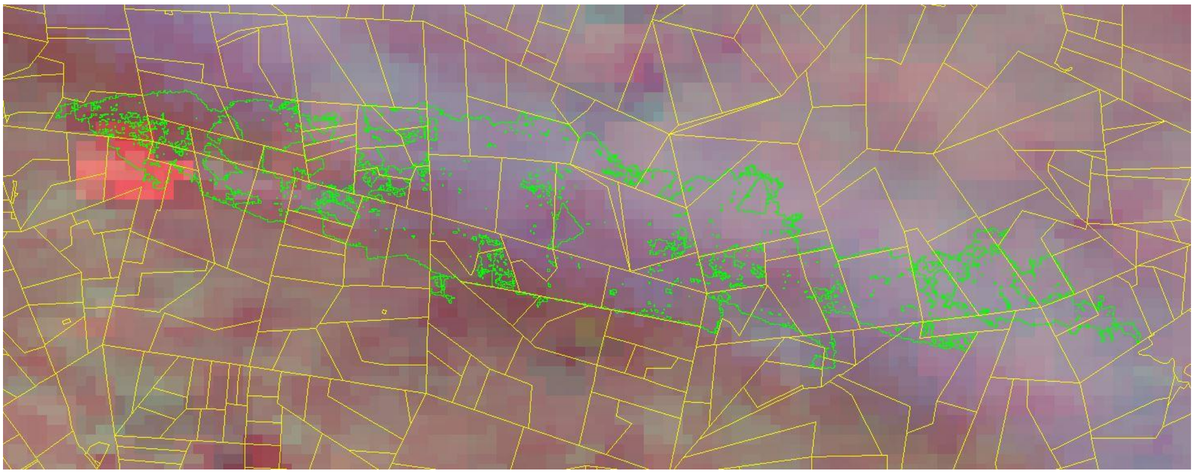

Figure 4.21: MODIS image of 30 August 2008 at 14:20 with the farm boundaries indicated by the yellow lines and the final fire scar indicated by the green lines.

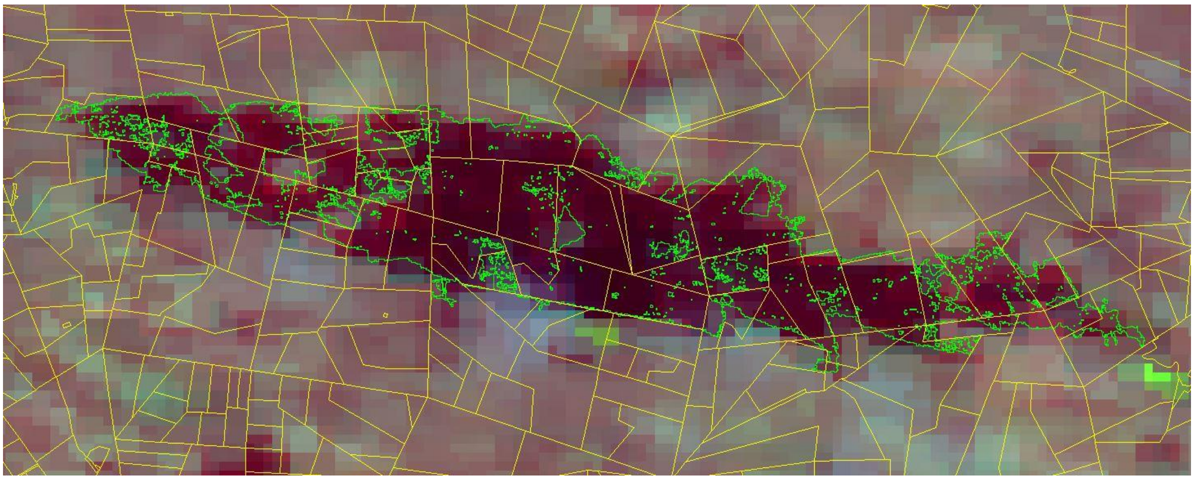

Figure 4.22: MODIS image of 31 August 2008 at 10:40 with the farm boundaries indicated by the yellow lines and the final fire scar indicated by the green lines.

4.3.6. Vectorized area and area determination

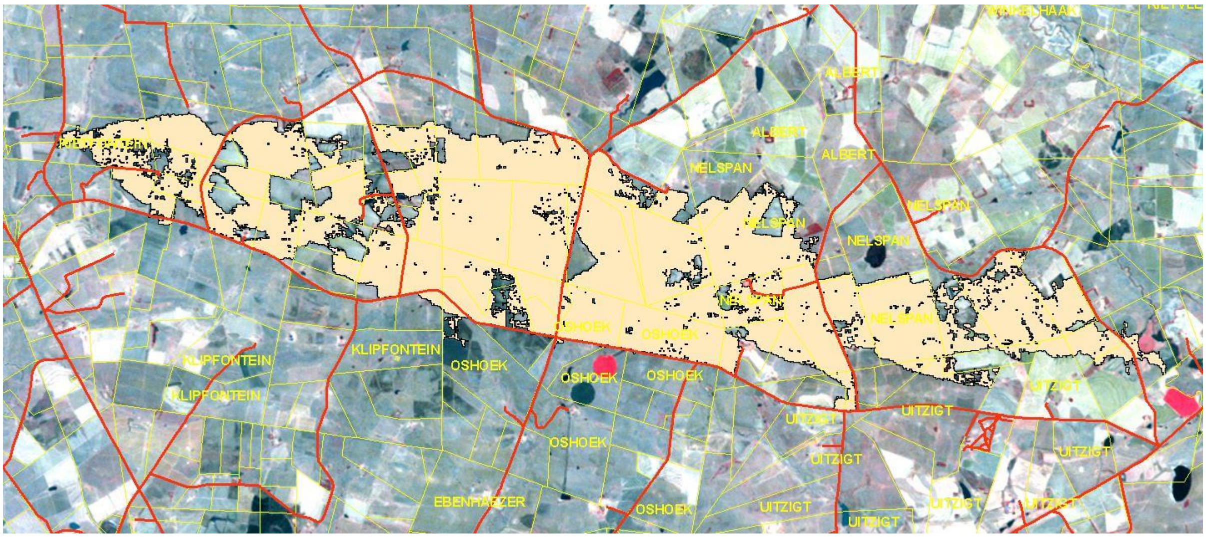

Figure 4.23: The vectorized fire scar on the Landsat image of 4 September 2008

The classified fire scar (figure 4.19) was vectorized, as seen in figure 4.23. The area was calculated and the destroyed area was approximately 7 522.73 hectares.

4.3.7. Additional information datasets

The farms layer was used to determine the areas per farm that was destroyed in the Bethal area. In order to calculate a quantum claim after a fire, each farmer needs to know how much of his farm was destroyed. In the case of a grass veld area, as found in the Bethal region, the land cover dataset did not contribute enough because it was mostly grazing grass that was destroyed. Figure 4.24 and figure 4.25 indicate the fire scar that is divided into the different farm portions.

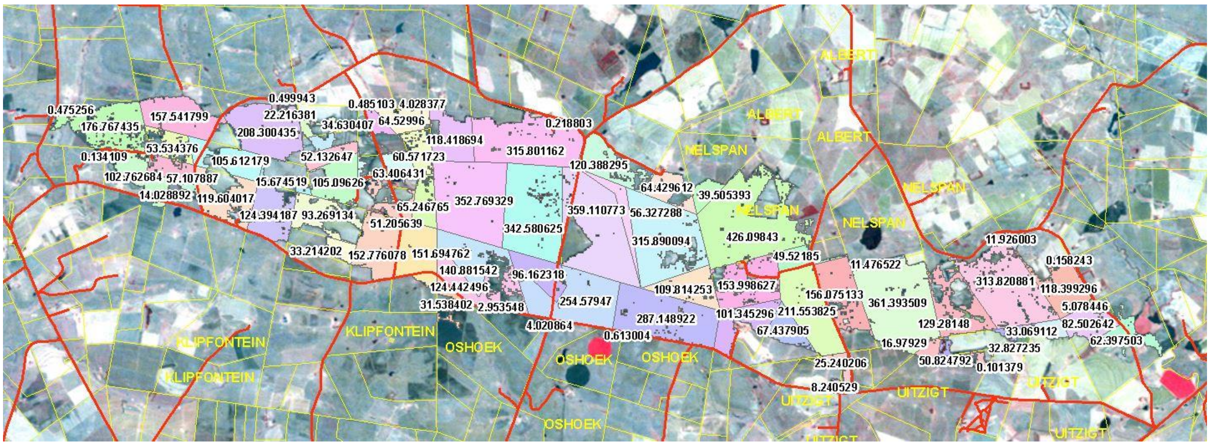

Figure 4.24: Indication of the areas per farm in hectares that was destroyed

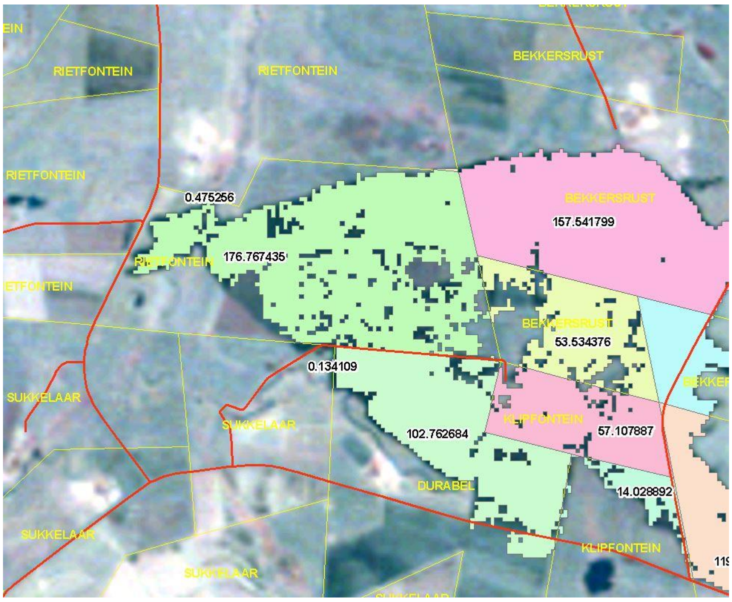

Figure 4.25: Indication of the areas per farm in hectares that was destroyed (zoom-in)

4.3.8. Probable starting point of the fire

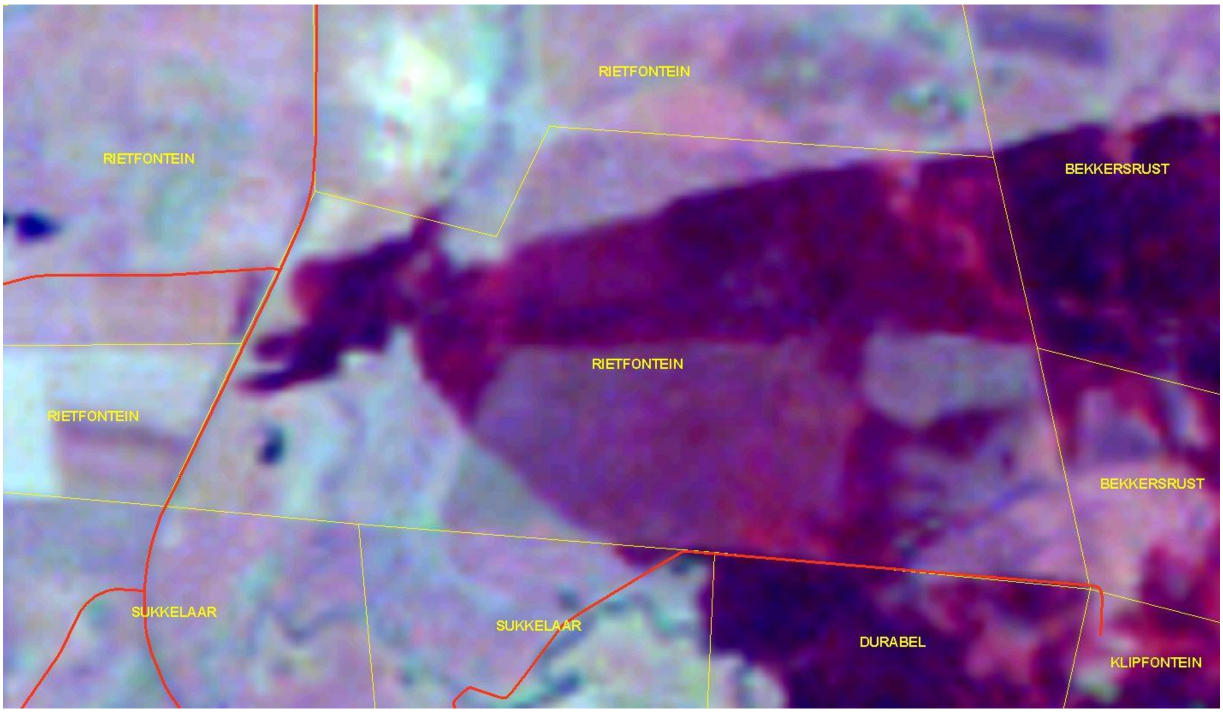

Figure 4.26: Landsat 5 image of 4 September 2008 with the starting point of the fire.

The probable starting point is clearly visible in figure 4.26. The red vector lines form part of the roads. It is clear that the fire started next to the road, as seen in figure 4.26. An Eskom line probably runs next to the road. A strong westerly wind blew, and that caused clashing of the power lines. The clashes caused hot metal to fall to the ground, which led to a veld fire.

4.4. Case Study 3 – Fire near Carletonville

4.4.1. Description of the terrain

The town of Carletonville is situated on the eastern side of the North West Province. There are lot of gold mines in the vicinity of Carletonville. The main farming activities are maize crops and cattle farming. During the winter of 2011, strong northerly winds raged through the North West Province. Many veld fires occurred during that time and due to the strong winds, some of those fires caused extensive damage. The fire scar on the western side of Carletonville is evidence of a fire that started on 23 August 2011. It burned in a southerly direction due to strong northerly winds.

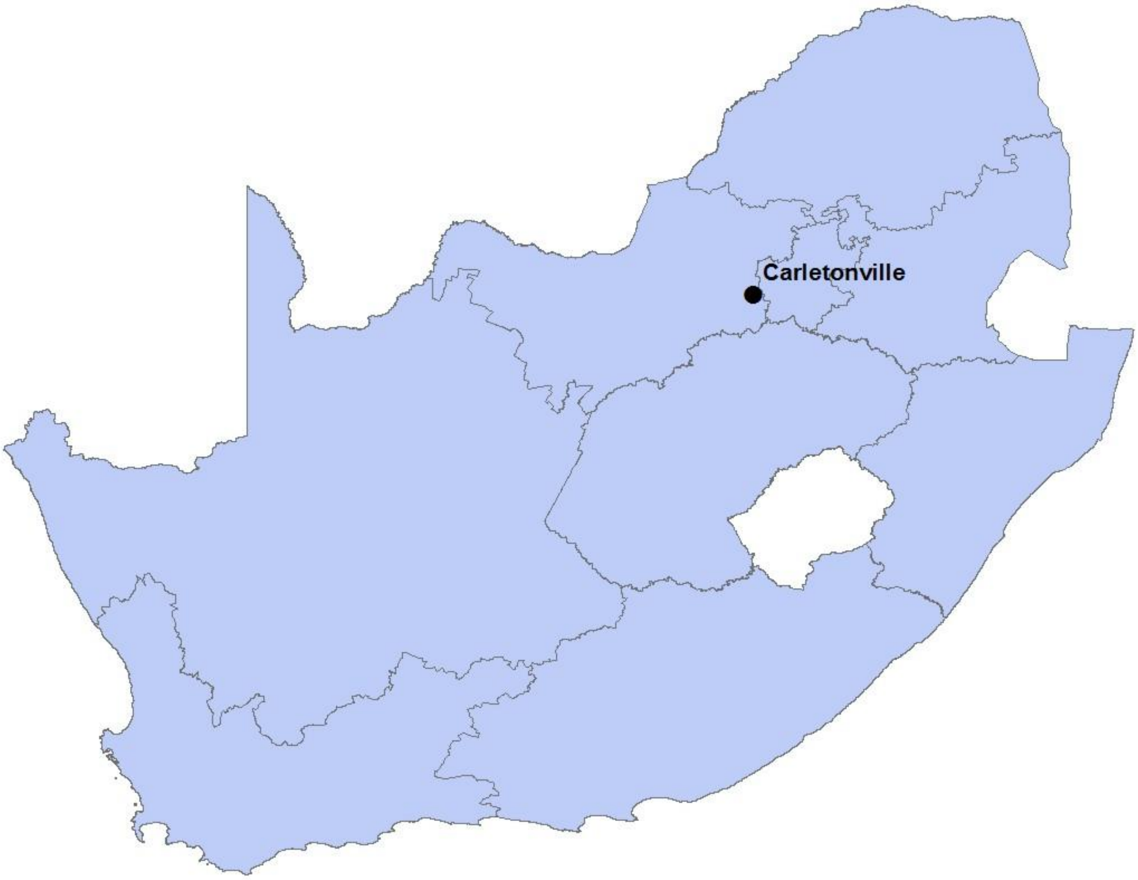

Figure 4.27: Indication of the town of Carletonville, next to the area of interest

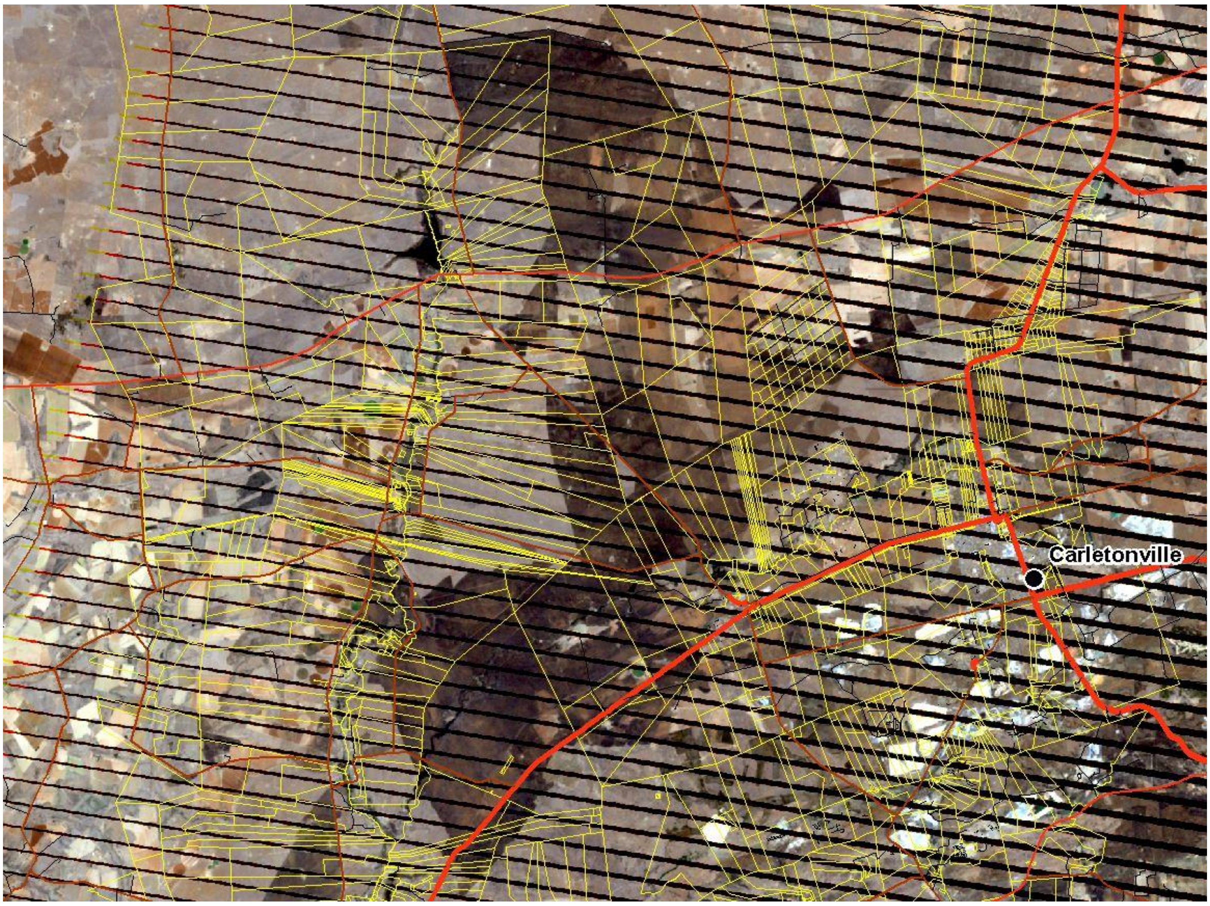

Figure 4.28: A Landsat 7 image of 4 September 2011 with the town of Carletonville. The yellow lines indicate the farm boundaries and the red and brown lines indicate the roads. The black lines on the image are caused by an anomaly on the satellite.

Figure 4.28 indicates a true colour combination of Landsat 7 on 4 September 2011. The true colour band combination exists out of bands 3, 2, 1 indicated by red, green and blue. The black lines in the image are caused by an anomaly on board of the satellite (Landsat 7). The scan line corrector stopped working in 2003. With the use of true colour, it is hard to distinguish between burnt areas, clear water and forested areas.

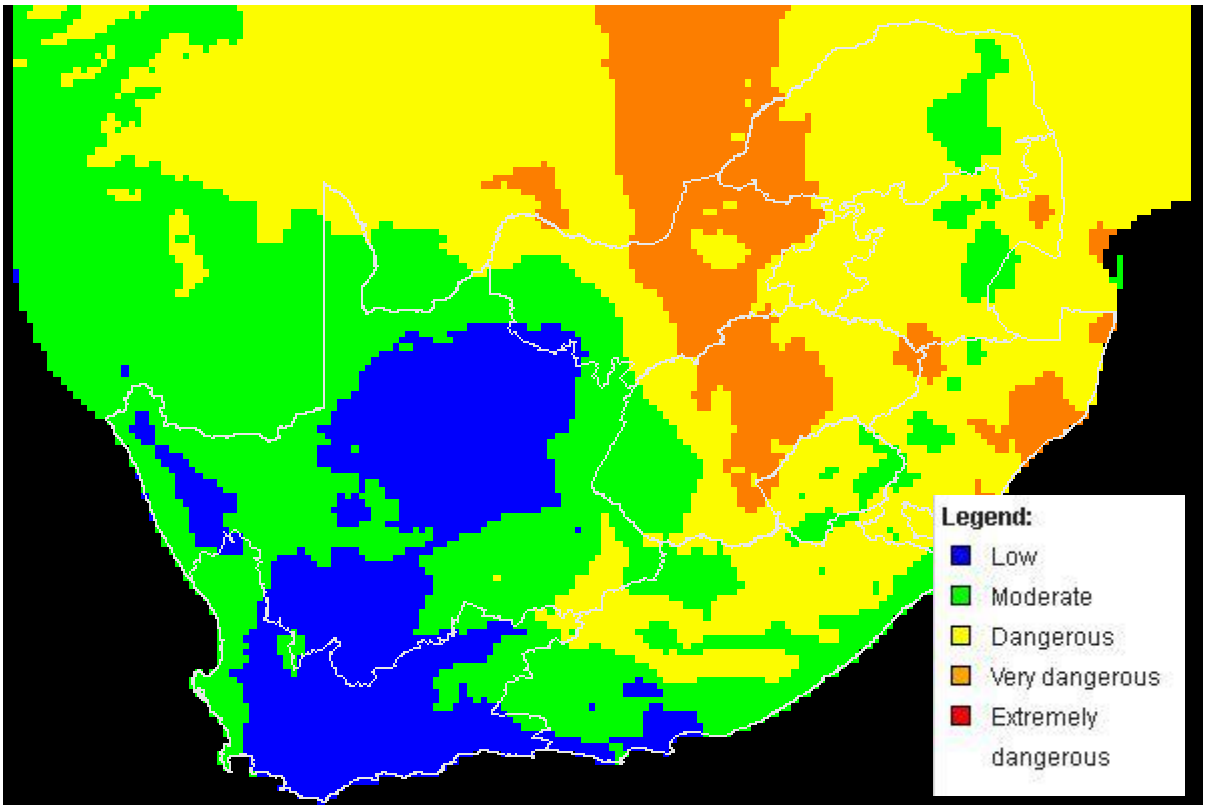

Figure 4.29: Fire danger map of South Africa as on 30 August 2008

Figure 4.29 is an example of a fire danger map. Such maps are available on a daily basis from AFIS. It gives a good indication of what the fire warning index was on the day of the fire. The fire danger map is also based on MODIS data.

On 30 August 2008, the fire danger map indicated the warning “very dangerous” in the Carletonville area (figure 4.27). The high wind speeds on that day resulted in a large fire scar.

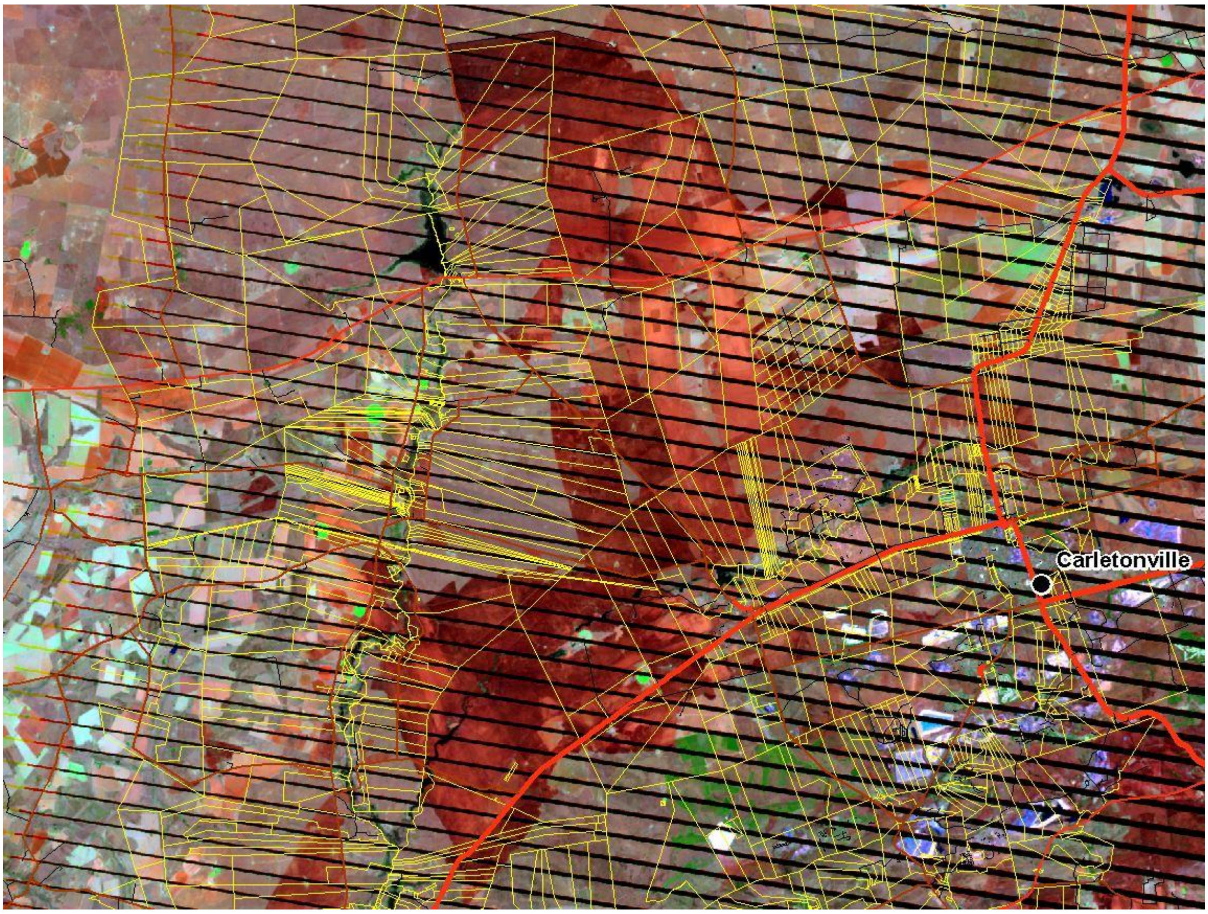

Figure 4.30: A Landsat 7 image of 4 September 2011 with the town of Carletonville. The yellow lines indicate the farm boundaries and the red and brown lines indicate the roads. The black lines on the image are caused by an anomaly on the satellite.

Figure 4.30 indicates the same fire scar as that of figure 4.28, but in false colour, with the combination 7, 4, 1 indicated by red, green and blue. The fire scar is better emphasized and more defined.

4.4.2. The data used

Landsat and MODIS data were used in this study. Landsat 7 data was used, as Landsat 5 data is no longer available because the satellite had limited use only after 30 years in orbit. Only one Landsat image could be obtained and no SPOT data could be obtained. A very good temporal dataset of MODIS data was available for this study.

4.4.3. Rectification and application of the indices

The Landsat data obtained had already been corrected with the UTM, Zone 35 projection. The MODIS data was obtained from SANSA and had the same type of correction as in previous case studies. As in the other case studies, the calculated indices were added to the original Landsat data as well.

4.4.4. Classification

Figure 4.31 indicates a supervised classification that was done on the Landsat data with the added indices. The red areas indicate the fire scars. The other classes in the classification were not important. Just as a matter of interest, the green indicates agricultural areas and the dark green indicates forested areas or areas with trees or bushes. The different colours in tan indicate grasslands and the turquoise colour indicates water and built-up areas.

Figure 4.31: A supervised classification of the Landsat 7 image of 4 September 2011. The black lines are caused by an anomaly on the satellite and the yellow lines indicate the farm boundaries.

4.4.5. The spread of the fire calculated from AFIS

The dots in figure 4.32 was obtained from AFIS and originated from the MODIS sensor. The red dots indicate where the fire started on 22 August 2011 at 13:32 on the farm Somerville.

The fire was detected again on 23 August 2011 at 09:55 and indicated by the yellow dots. At 14:14 on 23 August 2011, a strong wind blew and chased the fire towards the south, as indicated by the green dots. Another fire was detected at the same time (14:14) on the western side of the scar, in the vicinity of the farm Rooidraai and is also indicated by green dots.

In this case, the band combination of the Landsat 7 was 4, 3, 2 indicated by red, green and blue. In this case, the fire scar showed up in black, the active vegetation in red and the grasslands in a greenish colour.

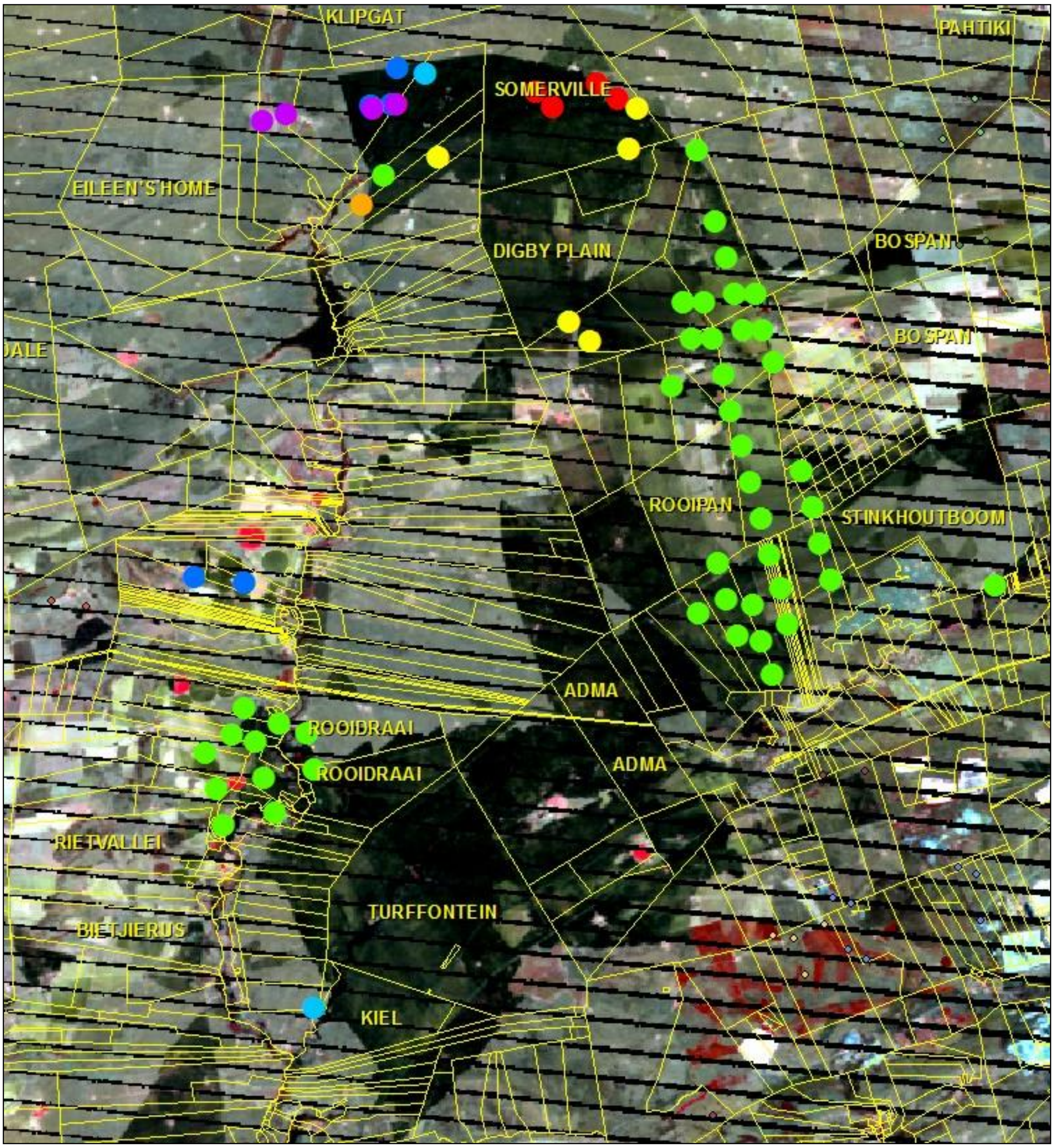

Figure 4.32: Dots obtained from AFIS with the Landsat 7 data as backdrop

With a closer look at the MODIS data of 22 August 2011 at 13:32, one can see that a part of the fire scar had already been there. The new fire is clearly visible on the farm Somerville, which is indicated by the red dots on figure 4.32. In figure 4.33, a red glow (the active fire) is visible on the farm Somerville.

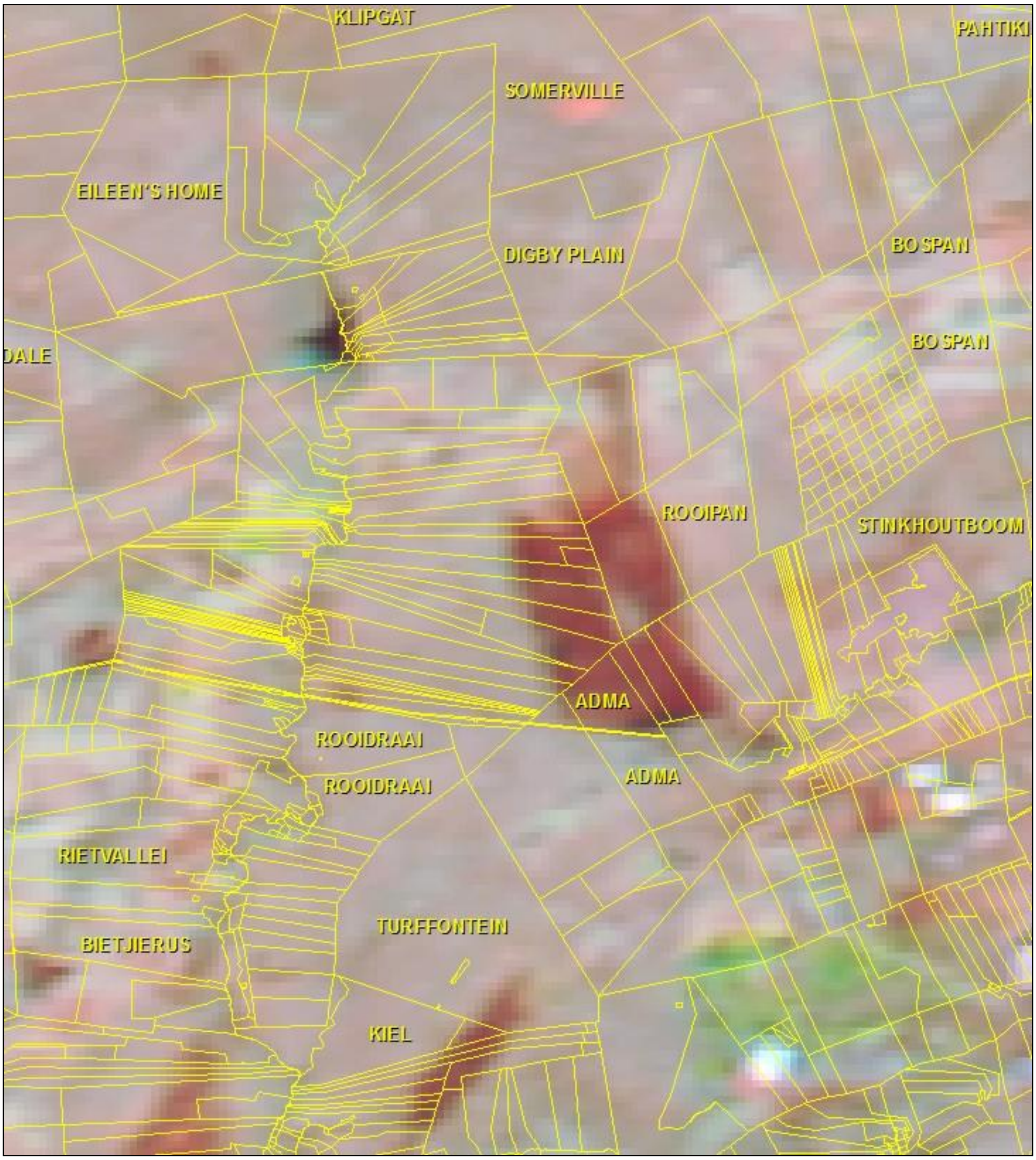

Figure 4.33: MODIS image of 22 August 2011 at 13:32

In figure 4.34, the fire progressed in a southerly direction. It destroyed the southern parts of the farm Somerville and most of the farm Digby Plain. A few fires are still visible on the edges and are indicated by the yellow dots in figure 4.32.

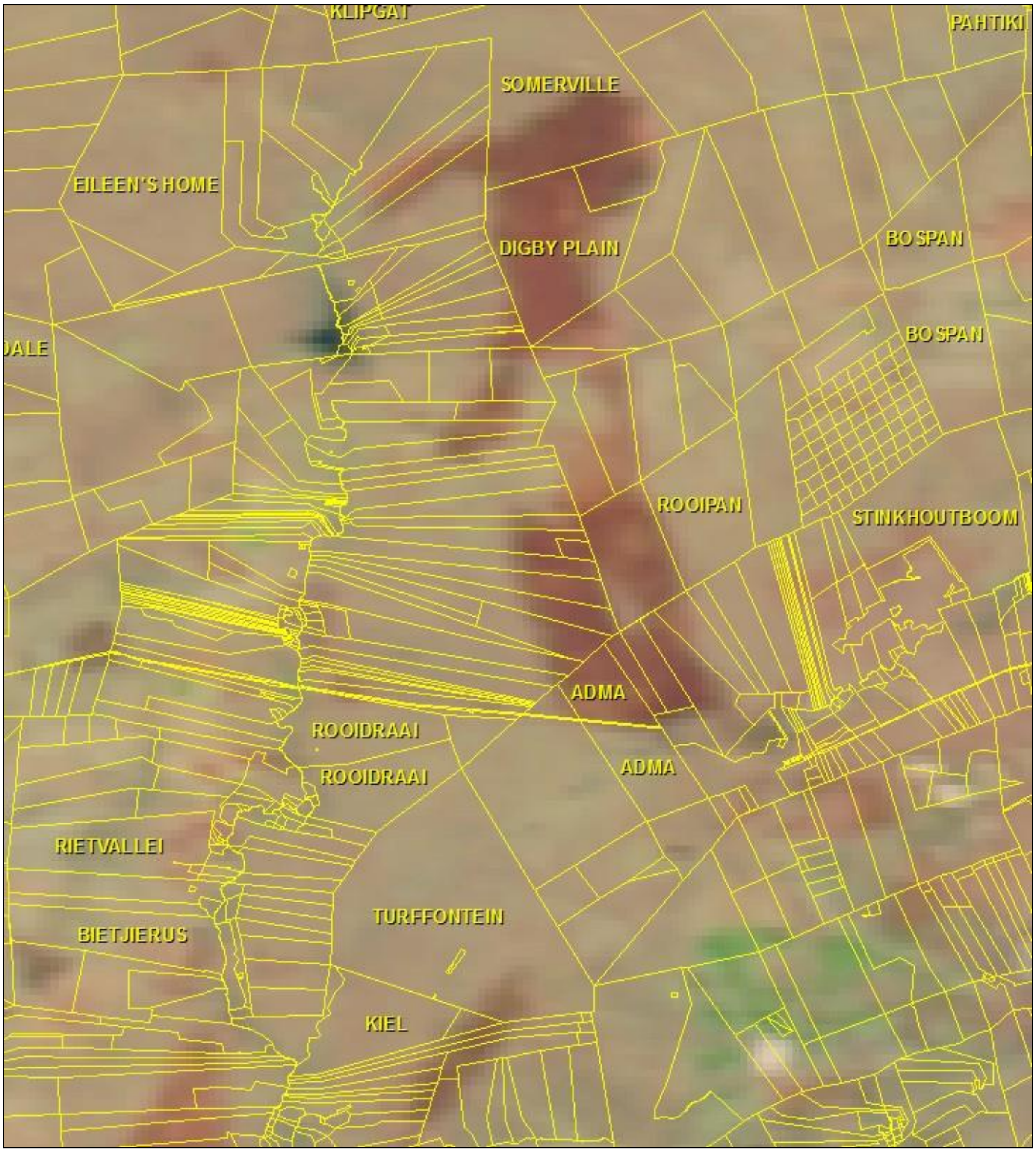

Figure 4.34: MODIS data of 23 August 2011 at 09:55

On the afternoon of 23 August 2011 at 14:14, a strong northerly wind caused huge fire damage (figure 4.35). This fire could not be stopped. Another fire started on the western side of the farm Rooidraai, west of the now existing fire scar. These two fires are indicated by the green dots in figure 4.32.

Figure 4.35: MODIS data of 23 August 2011 at 14:14

The strong wind later turned into a westerly wind and can be seen on the fire scar in figure 4.36. The fire burned in an easterly direction. The Somerville fire did not burn a lot towards the east. The Rooidraai fire caused extensive damage.

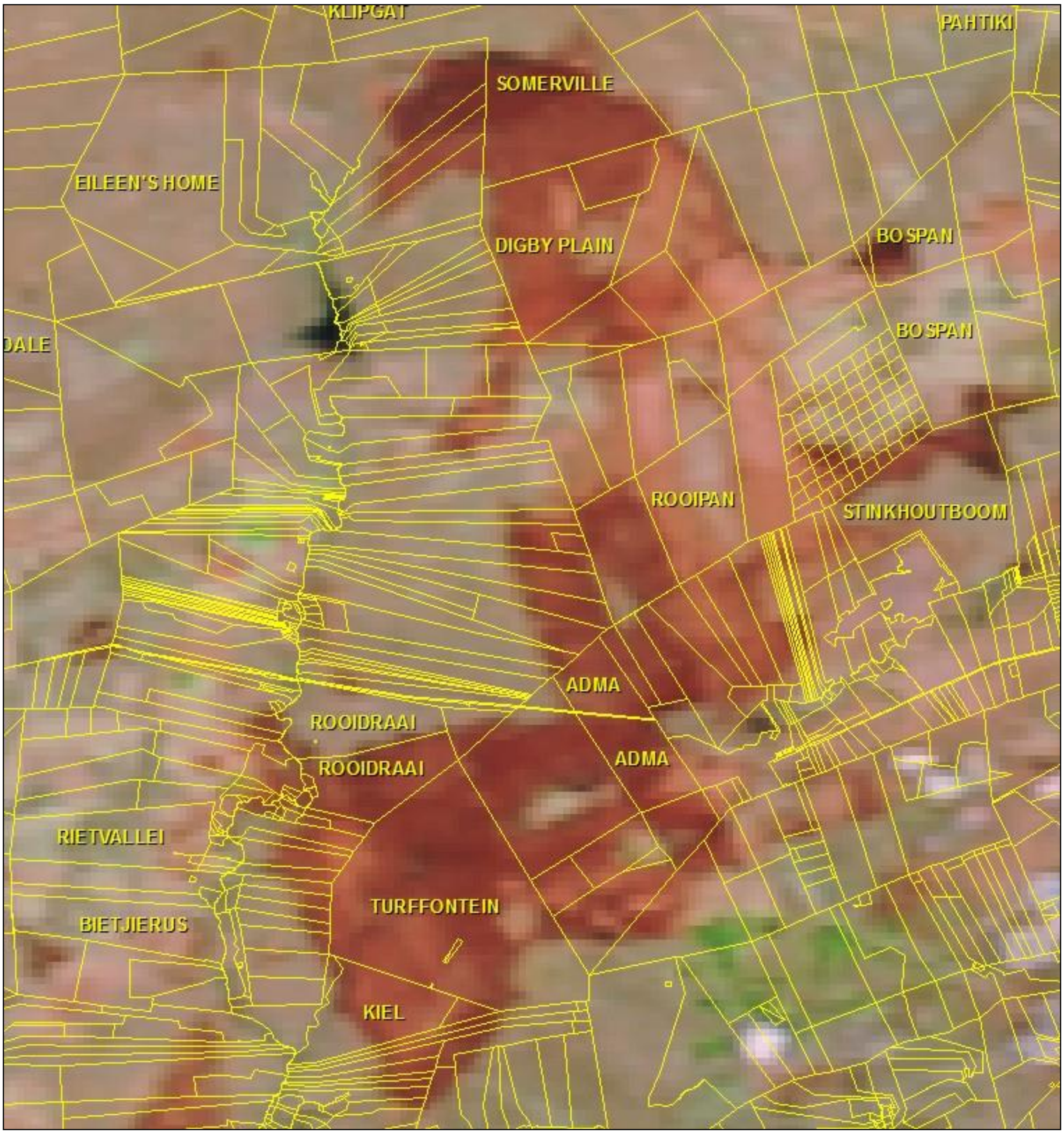

Figure 4.36: MODIS data of 24 August 2011 at 10:38

4.4.6. Probable starting points of the fires

Figure 4.37 indicates a subset of the Landsat 7 image of 4 September 2011, superimposed on a part of the 1:50 000 map of the Surveyor General of South Africa. That gave a better perspective to determine the starting point of the fire. The thin yellow lines indicate the Eskom distribution network.

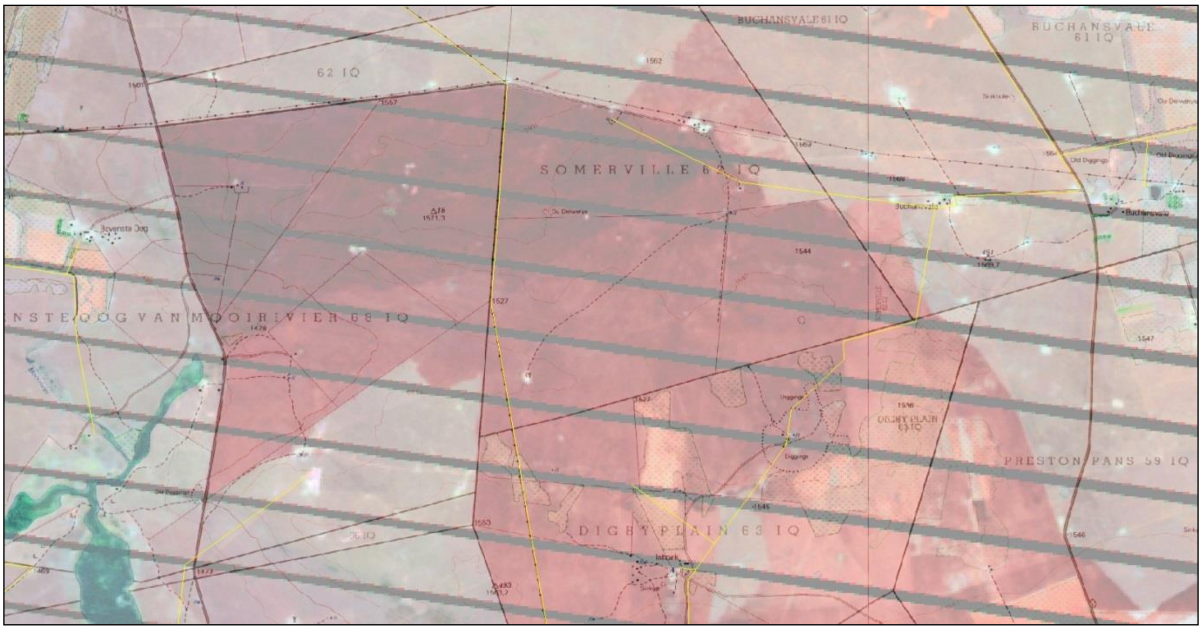

Figure 4.37: Probable starting points of the northern fires

The first fire (the fire of 22 August 2011) that started on the farm Somerville probably started in the area where the road and the yellow line cross each other in figure 4.37. The second fire (the fire of 23 August 2011) started on the farm Buchansvale just east of the farm Somerville, also probably next to the yellow line.

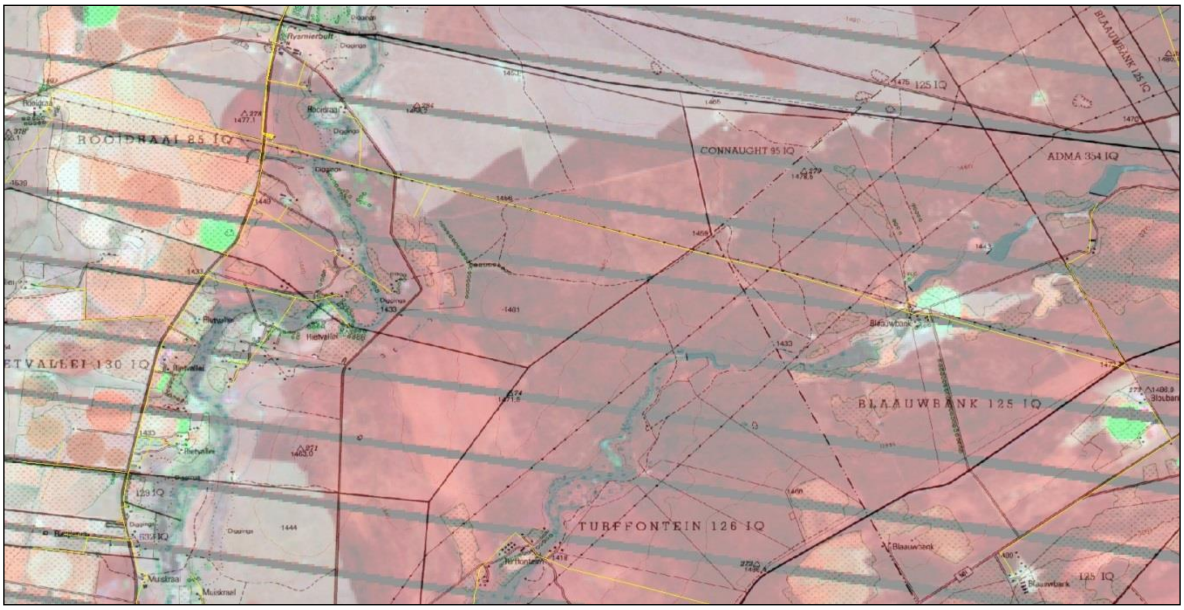

Figure 4.38: Possible starting point of the western fire

The third fire (the second fire of 23 August 2011) started in the western part of the total fire scar. The Rooidraai fire started just south of the road crossing (top left of figure 4.38). It probably started in a rubbish dump.

4.4.7. Vectorized area and area determination

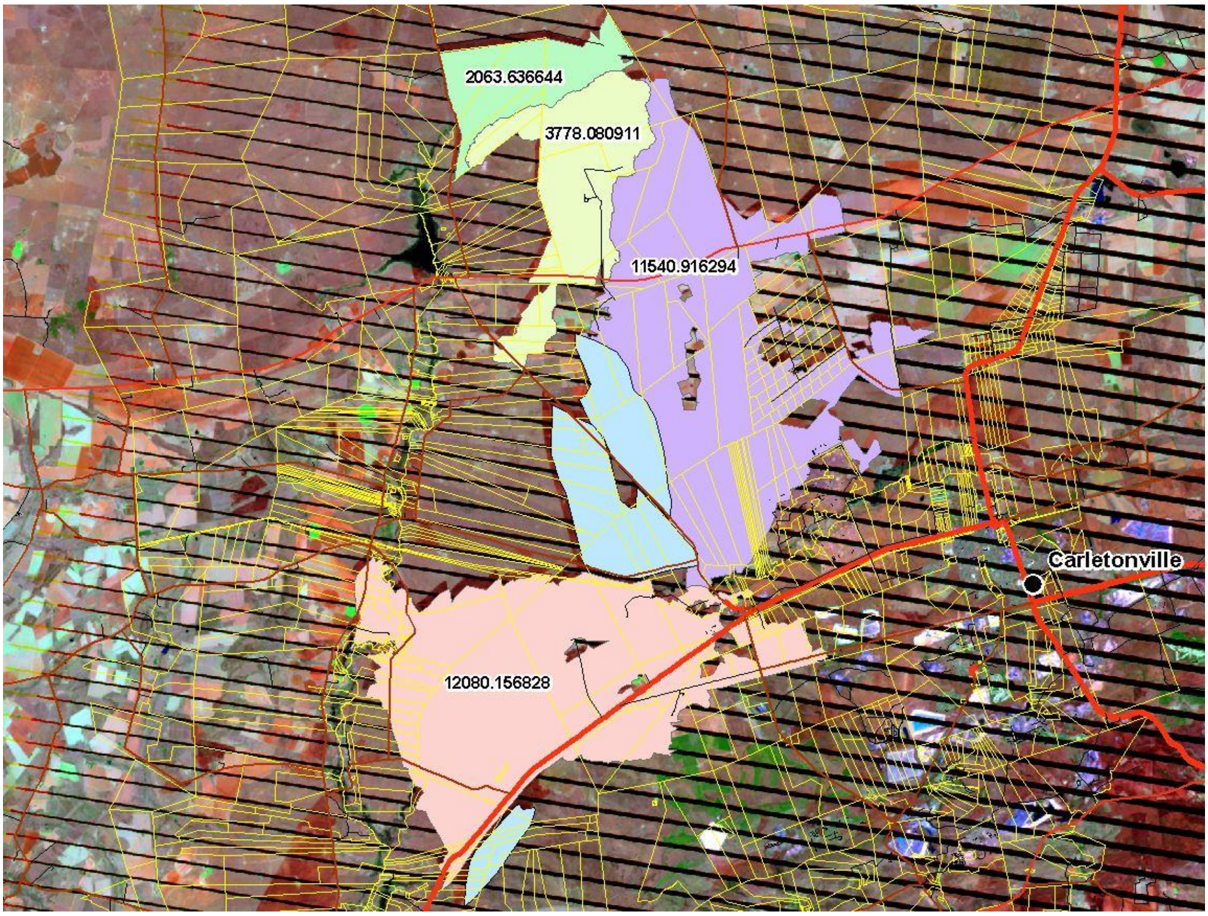

Figure 4.39: The fire scars were vectorized to determine the different areas.

The light green area indicates the fire that initially burned on the farm Somerville, which started on 22 August 2011. The approximate area destroyed by that fire was 3 778.08 hectares. The green area just north of this scar forms part of the light green area, but burned a little bit later because of a re-ignition of the fire. The approximate area was 2 063.64 hectares. The second fire that started on the farm Somerville on 23 August 2011 is indicated by the purple area. The approximate area destroyed was 11 540.92 hectares. The Rooidraai fire which also burned on 23 August 2011 is indicated by the pink and the approximate area destroyed was

12 080.16 hectares. The blue areas indicate the old fire scars and their areas were not calculated.

Chapter 5: Results and Conclusions

5.1 Introduction

This chapter deals with the conclusions and recommendations of wildfire investigations. The conclusions point out some of the advantages and disadvantages of using optical satellite imagery. One big advantage is the use of Landsat data because of the spectral depth and the regular revisit times. One of the disadvantages of optical imagery (i.e. Landsat) is that the starting point of a fire cannot always be determined.

5.2 Conclusions

The aim of this research was to determine the fire scar as indicated by where it burned and to find suitable imagery. It was found that Landsat was the most suitable sensor because it revisited the same area on a regular basis. That meant that there was a huge archive of images to choose from. Spot data could be used, but the irregularity of the revisit times of the sensor on specific areas made it unreliable. Furthermore, the spectral depth of Landsat was better than that of SPOT and it resulted in better determination of indices. By using classification, the fire scars could be determined. The role of the slightly better ground resolution of 20m of SPOT in comparison to the 30m of Landsat did not make a big difference in determining the area of the fire scars.

Valuable data to follow the progress of a fire was obtained from the AFIS system. In the case of the Sabie fire, the first few hours were successfully determined by tracking the fire with the use of the information obtained from the MSG satellite. The later hours from the AFIS could be used but was impractical to put in the report for this study. In the case of the Carletonville fire, the fire scars could be analysed with the aid of AFIS and the MODIS sensor by pulling it apart. That made it possible to determine different fire scars and prevented putting the blame on only one individual. It was not always possible to locate wind data for the areas where the fires burned, but useful data was obtained from nearby weather stations and the smoke plumes on the MODIS data.

The classified data was vectorized in a GIS (geographic information system) and the fire scars were extracted from it. The fire scar areas were calculated and the areas smaller than one hectare were deleted because the smallest sensible unit on Landsat is about one hectare. From all the fire scars per image, the fire scar under investigation was then separated and the area was calculated. In combination with the other datasets (mentioned above), the type of vegetation and/or the farm unit that was destroyed by the fire was determined.

Optical satellite imagery was successfully used to determine the extent of the fire scars. The determination of the starting points of the fires however was not always successful. The Sabie fire had a starting point that was more or less identifiable. The exact point could not be determined. For the other case studies the starting point of a fire was determined. The Bethal fire, for example, had a very well-defined starting point and the spread of the fire was what one would expected in the case of a strong wind; it formed an ellipsoidal pattern. The determination of firebreaks with the aid of satellite imagery was not determined through this study. Sometimes a firebreak can be determined, but the size of the firebreak, the spatial resolution of the satellite and the date of the satellite image are the determining factors. When fires burned into each other, it was not always possible to determine the extent of the fire scars, but in the Carletonville fire, three well-defined starting points could be identified. The spread of those fires were more indefinite because the wind changed from time to time. Old fire scars also played a role in determining the newer scars. With the aid of MODIS data, the fire scars could be separated. The calculations of the old fire scars were not very accurate because of the low spatial resolution of the MODIS sensor, but accurate enough to make a meaningful calculation of the new fire scars.

5.3. Recommendations

With the use of fire indices, the severity of a fire scar can be determined. In the case of forest fires, severity might be helpful to determine the burn completeness in a plantation. In legal cases, most people are only interested in where the fire started and what area was destroyed.

For fire modelling a few parameters are needed, namely the following: An elevation model, because terrain plays a crucial role; fuel models, because vegetation (biomass) is needed to burn; moisture of the fuel, because wet vegetation does not burn easily; and weather conditions such as hot, dry days and wind (Finney, 1998). Biomass calculations help to calculate the burn severity and can also be very helpful in fire modelling. In the case of the Carletonville fire, more information can be obtained with the aid of fire modelling on how the different fires burned. A more accurate determination of the different fire scars can possibly be calculated. The starting point of the Sabie fire could probably have been determined by using modelling. Wind data is also very useful in fire modelling.

Further useful information will be a reliable source of historical wind data. In most cases, it was difficult to obtain reliable wind data.

This year (2013), two new satellites (Landsat 8 and SPOT 6) were launched and they will be helpful in the determination of fire scars. Landsat 8 has eleven spectral bands and SPOT 6 has four spectral bands. SPOT 6 will not be a suitable sensor because the short-wave infrared band (SWIR) that was available on SPOT 4 and SPOT 5 was replaced by a blue band. That gives SPOT 6 the opportunity to have a true colour image, which is not suitable for fire analysis. With these satellites, together with the existing satellites such as Landsat 7 and SPOT 5, a greater revisit frequency will be possible.

With remote sensing and GIS fire investigations can successfully been done to solve legal disputes. It will become a very popular way of doing fire investigations, because this method is a lot cheaper than with the use of aerial photo investigations. Another advantage of this fire investigation method is the existence of a large archive of satellite imagery.

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