Review of Swaziland fire disaster using GIS and MODIS data

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During the month of July 2007, a series of fires erupted throughout Swaziland destroying property and resulting in the loss of lives in various parts of the country. In this article, a demonstration is made on the use of geo-referenced data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on board NASA’s Aqua and Terra satellites to review the disaster.

Scientific evidence exists to suggest that savanna ecosystems evolved and adapted with fire as an agent of ecological change. However, human activities have altered many natural landscapes and placed human beings in direct contact with fire or fire sources. Fires are known to cause loss of human life and personal property, economic upsets, and disturbances in regional and global atmospheric composition and chemistry, and climate. It is the goal of any fire manager or relevant authority to respond appropriately to fires to best protect and preserve the resources at risk in line with local policy objectives.

Fires are either caused by human activities or natural phenomena such as lightning or volcanoes depending on the place and time of the fire. Fires that are caused by humans can be characterised as either intentional (such as in the case of arson) or accidental (e.g. runaway prescribed fires) and are indicative of the complex socioeconomic settings within which they occur.

It is basic scientific knowledge that for fire to occur, three elements are necessary for combustion, namely heat, oxygen and fuel [1]. Another triangle of primary conditions that can affect extreme wildfire behaviour consists of topography, fuels, and weather. Hot, dry, and windy conditions are generally ideal for the rapid growth and spread of wildfires. Steeper slopes tend to increase the rate of fire spread. These conditions often persist over Swaziland, more especially in western half of the country, in association with the El Niño Southern Oscillation (ENSO) warm phase. As the synoptic weather pattern changes within the climatic conditions, periods of critical fire weather and fire behaviour can develop.

In late July 2007, an environmental and economic disaster unfolded in the kingdom of Swaziland when the country experienced a series of devastating fires. Propelled by high wind speeds and a prolonged dry season, the fires resulted in damage to thousands of hectares of forest and other vegetation, and direct economic losses estimated in the hundreds of millions of Emalangeni (at par with the South African Rand). This culminated in the declaration of these fires by the country’s prime minister as a national disaster on 1 August 2007. A report by the Ministry of Regional Affairs and Youth Affairs, which also houses the Disaster Management Agency, puts the number of homesteads destroyed at 169 and the total number of affected people at 934 with two casualties [2].

Smoke pollution was evident as the sky was darkened by plumes from the same fires. Various media reports suggest acts of arson and negligence. Whilst these may not be ignored it is critical to understand the underlying eco-climatic factors which may have accelerated and exacerbated the impact of these fires. Typically in Swaziland, the driest months of the year occur in the winter, i.e. from around April to September. When the ENSO warm phase is established, an anomalous dry and warm pattern can be significantly amplified, as it has been in the past two to three years. Swaziland’s topographic outlay, especially the higher altitude areas, can often be the cause of extreme weather conditions which may amplify fire behavior.

Study area

The Kingdom of Swaziland, located in southern Africa, is characterised by complex topography with elevation that decreases from an average of 1400 m on the west to below 100 m above sea level on the eastern part of the country giving rise to four major eco-climatic (commonly referred to as agro-ecological) regions, namely the near-temperate Highveld, sub-tropical Middleveld, the semi-arid Lowveld and the Lubombo Plateau.

Climatic variations within the country are largely controlled by the topography resulting in four seasons with December being mid-summer and June mid-winter. Mean annual rainfall is highest in the Highveld varying between 1000 and 2000 mm depending on the year. Eastwards, the Lowveld records between 500 to 900 mm per annum. Variations in temperature also follow the altitudinal gradients, the Highveld being temperate and seldom hot while the Lowveld records temperatures of up to 40°C during summer.

Data analyses

A major step forward has been the successful launch in 1999 and 2002 of MODIS on board the morning descending Terra and afternoon ascending Aqua polar orbiting NASA satellites, thus offering the opportunity to detect fires both day and night with little data gaps. The MODIS sensor design includes bands specifically selected for fire and cloud detection and allows the retrieval of sub-pixel fire area and temperature. A dataset of active fires from 22 July 2007 to 31 July 2006 was used. This dataset is based on the version 4 contextual fire detection algorithm MODIS Rapid Response System (Web Fire Mapper, http://maps.geog.umd.edu/) at a spatial resolution of 1 km [3][4].

To explore the fire hotspot distribution, active fire data was downloaded from...
the MODIS Rapid Response System. The centre points of 1 km MODIS fire pixels with a confidence level above 0% were considered individual fire counts and these were then imported into a GIS (ArcGIS 9.2) for mapping and analysis. Fire hotspot counts were then conducted for each administrative region and land cover type as an indicator of the extent of the fire activity.

To assess vegetation condition, observational indices have been developed and are used by fire and forestry agencies to assess drought and potentially extreme fire danger. The Normalised Difference Vegetation Index (NDVI) is a commonly used indicator of vegetation condition and has been used in conjunction with other meteorological variables to estimate line and dead fuel size and quantity, and therefore as an indicator of fuel condition to determine fire danger ratings.

The MODIS 16-day MODIS/NDVI Time Series data covering the study area were acquired from the Global Agriculture Monitoring (GLAM) Project (http://pekko.geog.umd.edu/usda/demo1/) for the period January 2000 to July 2007 to examine vegetation conditions over the recent past for the four regions of the country. Although this dataset has a spatial resolution of 250 m, it does provide a very effective source for the examination of intra- and inter-annual variations in vegetation conditions because of its high temporal resolution. The deviation from the 2001 - 2007 average for each two-week period was calculated and compared with the commonly used ENSO index, the Southern Oscillation Index (SOI) to characterise the influence of El Niño.

**Results and discussion**

A combination of Moderate Resolution Imaging Spectroradiometer (MODIS) rapid response imagery and near-real-time reporting of fire detection was crucial in determining the extent of this disaster. By the end of July 2007, hot spot counts (fire pixels in satellite images) for the country had begun to climb and preliminary analysis indicates that this has exceeded the annual number for all years since 2001, and anecdotal reports of fires damaging property, injuring and killing people had flooded the local media. The volume and extent of smoke plumes from these fires were highly visible from 700 km up in space and as can be seen from Fig. 1, almost the whole country was covered in smoke.

A total of 1418 hotspots were detected by MODIS over the ten day period under investigation - the majority (78.3%) of which was detected from the 27 July 2007 image. The hotspot counts reveal that the region most affected by the fires was Hhohho with 873 hotspots followed by Manzini (235) and Shiselweni (174) whilst the Lubombo region was least affected with 136 hotspots mainly from sugarcane field fires.

Although the cause or ignition point of these fires has not yet been ascertained, fires in Swaziland are used by people to facilitate pasture regeneration and in clearing vegetation for farming and settlements. Most people burn wooded areas and grasslands in an effort to improve grazing conditions. To minimise losses due to fires, commercial forest plantations have been designed with networks of firebreaks, which are burnt annually (especially between June and July) to provide a clean belt around the compartments [5].

Overlay analysis with a year 2002 land cover map reveals the expected pattern where most (42%) of the fires were detected within the forest plantations followed by grasslands, thickets/bushes (Table 1). This also confirms the impact of the current burning practices and the vegetation that was affected. A few fires were also detected within cultivated and residential areas, again reaffirming the use of fires for burning crop residue and the impact of the fires through burning down of settlements. It is however important to note the

<table>
<thead>
<tr>
<th>Land cover type</th>
<th>Percentage of total fire hotspots</th>
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</thead>
<tbody>
<tr>
<td>Cultivated: permanent - commercial sugarcane</td>
<td>1.29</td>
</tr>
<tr>
<td>Cultivated: temporary - semi-commercial/subsistence dryland</td>
<td>3.96</td>
</tr>
<tr>
<td>Degraded: unimproved grassland</td>
<td>5.77</td>
</tr>
<tr>
<td>Forest and woodland</td>
<td>2.15</td>
</tr>
<tr>
<td>Forest plantations</td>
<td>42.11</td>
</tr>
<tr>
<td>Thicket and bushland</td>
<td>20.76</td>
</tr>
<tr>
<td>Unimproved grassland</td>
<td>23.17</td>
</tr>
<tr>
<td>Urban built-up land: residential</td>
<td>0.78</td>
</tr>
</tbody>
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Table 1: Fire hotspots detected by land cover type.
differences in spatial resolution of the land cover map (30 m) and the fire pixels (1 km) which would not have been accurately correlated for smaller land cover features such as buildings.

The dramatic upsurge of the fires occurred on the 27 July fading down with days. From Fig. 2 it can be seen that these fires were mainly concentrated on the western half of the country where hundreds of hectares of forest plantations, homesteads and natural vegetation were burnt. The most evident cluster of fires is on the north-western part of the country where the Pigg’s Peak Timber and Mondi plantations companies reportedly lost hundreds of millions of Rands worth of property and an estimated 80% of the total forest area. It is in the same region where several homesteads were destroyed by the same fires.

There is also observed an evidence of transboundary fires between Swaziland and South Africa particularly on the south-western part of the boundaries (Fig. 2). It is important to observe from Fig. 1 that the fires in Swaziland erupted at around the same time as in neighbouring South Africa where there were also reports of extensive damage and loss of human lives. This situation points to the need for a coordinated multinational approach in the management of fires.

Fig. 2: MODIS fire hotspots (22 to 31 July 2007).
The topographic variations in the country can often generate the hot, dry, and windy environment needed for extreme fire behaviour. A majority of the areas affected by the fires are in high altitude areas of the Middleveld and Highveld with steep slopes that accelerated fire spread rates. During the period of the fires, high speed winds were prevalent in the country creating perfect conditions for the inferno.

Meteorological indications had earlier on suggested that anomalous drought conditions would occur again this year and this proved true when the national government declared the drought a national disaster. Since then, a lot of focus from the government was centered on providing food and water for drought victims unaware that another big and destructive disaster was looming. Research and results from several climate models suggest that El Niño-like conditions are likely to become more frequent in the future which subsequently means that fires in the near future will become the forerunners of larger disasters.

NDVI has been used to estimate water stress, and hence fire risk, in various parts of the world [6][7]. The effect of El Niño on vegetation in the region has been widely investigated and has been shown to result in drier vegetation conditions within the southern African region [8]. Fig. 3 reveals a negative NDVI deviation trend from the 2001-2007 mean due to the persistence of the El Niño-like conditions thereby increasing forest fire risk. In this study, the continually low values of NDVI obtained in the country, in the periods of 2006 and 2007, could therefore have been indicative of the looming disaster as manifested by the biggest fire disaster ever recorded in the country. Persistent negative SOI values indicates an El Niño episode which is linked with SST warming and sea level pressure decrease in the central and eastern Pacific. The SOI (Fig. 3) shows that since the year 2002, there have been several El Niño-like events with more pronounced evidence during the dry season (April to September) thereby cumulatively increasing vegetation dryness as evidenced by the corresponding decreasing trend in the NDVI. This illustrates the effects of the El Niño especially considering the high risk associated with the phyto-physiognomy of open grassland, savannas and forest plantations in the areas affected. Similarly, the risk of drought and fires in southern Africa has also been observed to increase dramatically in El Niño years [9][10].

It is also critical to note the dangers associated with wildland/urban interfaces which are common throughout the country where urban development towards vegetated wilderness areas in such cities and towns as Pigg's Peak, Mbabane and Manzini has confronted people with fires. In addition, this is the situation that has increased the risk and damage to people and property, and makes the fires more complex to fight due to the mixture of different fuels and structures in the interface.

The management of the interface between wildland and urban or settlement areas is a critical component of fire management strategy aimed at reducing the impact of fires on property and people. This requires an integrated approach that would take into account the fuel loads around these areas.

Conclusions and recommendations

Even though the ignition point or source of the fires has not been ascertained, climate variability, especially the ENSO cycle, coupled with suitable weather and vegetation conditions suggest that the recent periodic severe drought events and current fire management practices provided an enabling environment for the fire disaster in Swaziland.

There is an apparent relationship between the drought in Swaziland and a corresponding signal with respect to the magnitude of the disaster. Increasing population, the expansion of the urban/wildland interface, and the ever changing land use issues have also contributed to the large scale extreme fire behaviour and will continue to do so in the future. The evidence from satellite observations and basic GIS analysis provides evidence that the prolonged drought, aided with the country’s land and fire management practices had a significant contribution to the fire disaster.

This knowledge and experience might be used for fire prevention efforts, resource and logistics planning, and awareness of the population in general to the link between climate and local weather trends. Educational programmes, revision and amendment of the outdated Grass Fires Act of 1955, the development of a national fire disaster management strategy and the establishment of a fire information system are crucial elements in achieving an effective management and control system for fires.

Further investigation is also required to determine the interrelationships between fire, climate and land use in the country. Increasing observational and technological skill and experience at recognising dangerous fire weather scenarios, based on climatic and vegetation changes, may offer significant lead time to anticipate future disasters and minimise losses and environmental impacts. The capabilities of GIS and remote sensing applications, as demonstrated in this article, offer exceptional value for early warning, pre- and post-disaster assessment.
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References

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