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Identifying the extent of burned areas is essential to plan the necessary post-fire restoration measures. Photo: Harifidy Rakoto Ratsimba

Using satellite images to monitor burned areas in Madagascar

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Introduction

The conservation of Madagascar's unique natural heritage is a key concern of public authorities, and also attracts the attention of international organizations. One threat to the country's flora and fauna is the recurrence of wildfires. It is true that many of the country's forest landscapes have long been shaped by fire, but the increase in fire frequency and in the total burned area is having ever more negative impacts on ecosystems. Wildfires also affect livelihoods by burning the forests and even the farmland that people depend on. However, effective fire management remains a major challenge for natural resource managers in the country. A prerequisite is to first understand the extent of the problem, in order to plan both adaptation and response strategies. This requires accurate quantitative data on when and where fires are burning.

> ***"Fire monitoring through mapping of burned areas has a crucial role in designing appropriate fire management programmes."***

Since 2000, satellite monitoring of fires in near real-time has been widely popularized and used in Madagascar, mainly in and around protected

The ground covered with ash in an area recently burned by a very-high-intensity fire in Ankarafantsika National Park.
Photo: Dimby Raherinjatovoarison

areas. It has been used primarily to trigger alerts as part of early warning systems to increase the timely mobilization of firefighting responses. However, limitations have become apparent, especially in analysis of the impacts related to the frequency and extent of fires on the same burned surfaces.

This article reports on a study carried out in 2021 over an area of 1,575 ha in and around Ankarafantsika National Park in northwestern Madagascar using satellite images, drone images and ground-truth data to assess the accuracy and usefulness of mapping in quantifying burned areas. During that year, 13,073 ha were burned in the park (about 10% of its total area), predominantly in September and October. The park is not only home to exceptional biodiversity, but also plays a role in the economy of Boeny Region as a water regulator for the plains of Marovoay, one of the main rice-producing areas in the country. As a result, its protection and conservation are essential.

Quantifying burned surfaces

Burned areas are characterized by deposits of charcoal and ash, removal of vegetation, and change in the structure of vegetation (Boschetti et al. 2006). This leads to a change in the spectral behaviour of surfaces in time and space that can easily be tracked by remote sensing.

Images with low and medium spatial resolution are used to develop tools for monitoring burned surfaces. Many are taken by the Advanced Very High-Resolution Radiometer (AVHRR), the Geostationary Operational Environmental Satellite (GOES), and the Moderate Resolution Imaging Spectroradiometer (MODIS). MODIS is the most widely used sensor because it has the highest spatial resolution (500 m) and can detect active fires and thus allow decisions to be made quickly. However, even with its high resolution it is difficult for users to detect the extent of small fires, which are very frequent in tropical environments. The launch of Landsat 8 OLI in 2013 (30-m resolution) and Sentinel-2 MSI in 2015 (10-m and 20-m resolution), allowed the use of sensors with better spatial resolution (Mpakairi et al. 2020).

Evaluation of three sensors

Analyses in the study were carried out using MODIS, with the latest MCD64A1 collection, Landsat 8, and Sentinel-2. Images were acquired for the south of Ankarafantsika National Park between 15 and 17 October 2021 following specific fire events observed in the field. MODIS images from October 2021 were downloaded from the EarthExplorer platform and those from Landsat 8 and Sentinel-2 were directly processed and classified in the Google Earth Engine Cloud platform.

Spectral indices were used to better discriminate burned areas in satellite images; a combination of two or more indices improved classification (Bastarrika et al. 2011). Two common indices were used: (i) the Normalized Burn Ratio (NBR) and the Burned Area Index (BAI) for Landsat images; and (ii) the NBR and BAIS-2 (the improved version of BAI) for Sentinel-2 images (Filipponi 2018). As with other normalized spectral indices, the theoretical value of NBR varies between 1 and –1: a high value indicates good vegetation condition, while a low value indicates bare soil or a burned area (Key and Benson 2003). BAI does not have limit values, but in general, higher values indicate burned areas (Chuvieco et al. 2002); the index performs better in forested areas, where it highlights ash deposits (Mpakairi et al. 2020). For Landsat images, burned areas generally have an NBR between 0 and 0.3, and a BAI above 70 (Stroppiana et al. 2002). For Sentinel images, burned areas have an NBR lower than 0, and a BAIS-2 value higher than 0.87.

Results were then validated in three steps:

- First, field validation was undertaken to assess any errors related to the identification and estimation of burned areas. For this purpose, ground-truth data was recorded from 89 GPS points (Figure 1), a proportion comparable to studies in similar biogeographical areas (e.g., Axel 2018).
- Second, three error parameters were calculated to compare the performance of MODIS, Landsat 8 and Sentinel-2 sensors: error of omission (i.e., under-estimates), error of commission (i.e., over-estimates), and overall accuracy.
- Third, the three sensors were compared to true-colour images obtained from a flyby of a Mavic 2 pro quadcopter drone at 100-m altitude, with a spatial resolution of 5 cm, to evaluate any errors on the edges of burned areas due to the difference in spatial resolution of the sensors (Figure 2).

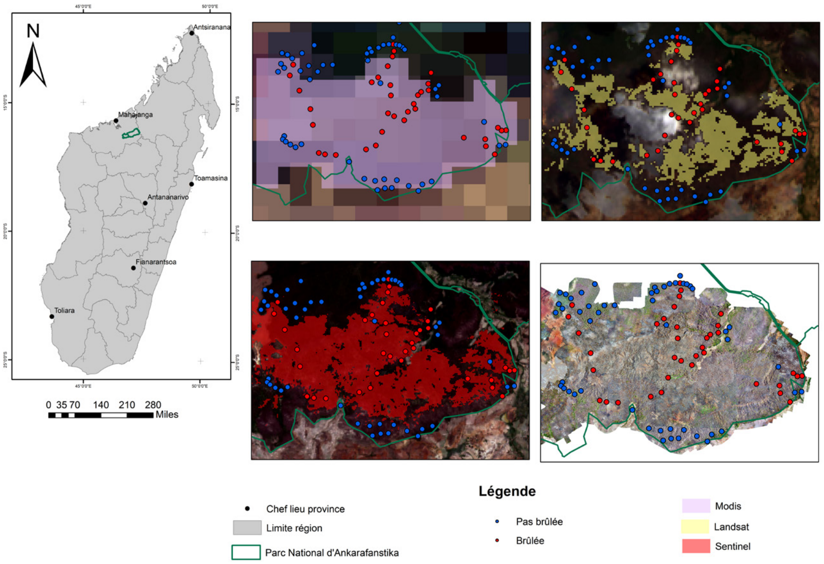

Figure 1. Field data used to validate burned area mapping from MODIS, Landsat 8 and Sentinel-2 in Ankarafantsika National Park.

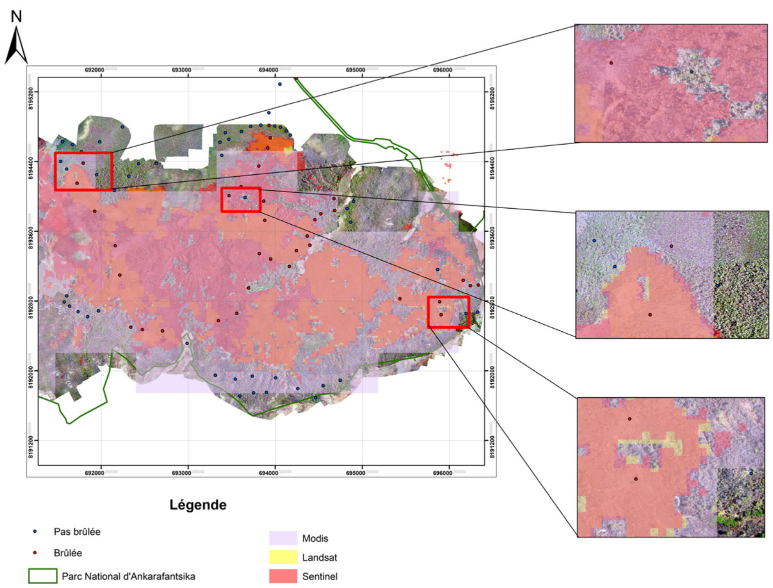

Figure 2. Errors observed on the edges of burned surfaces from MODIS, Landsat 8, Sentinel-2, compared to UAV true-colour images.

Aerial images allow users to determine the size of burned areas. Photo: Gaston Hedwigino Tahintsoa

Over an area of 1,575 ha in Ankarafantsika National Park, the three satellites gave very different estimates of burned forest, with 1,181 ha reported by MODIS; 330 ha by Landsat 8; and 656 ha by Sentinel-2. A comparison of commission error, omission error and overall accuracy was then required in order to accurately estimate the total burned area.

The MODIS sensor had a high commission error (57%) compared to Sentinel-2 (10%) and Landsat 8 (4%), meaning that more than half of the burned areas it detected were not actually affected by fire and were thus considerable overestimates. In contrast, Landsat 8 tended not to recognize many burned areas, having by far the highest omission error (73%), compared to Sentinel-2 (27%) and MODIS (16%). The cause of this error may be due to cloud cover on the image, or to underestimations linked to the presence of standing trees after fires.

Aerial images from the drones corresponded consistently with the ground data. The causes of the omission and commission errors from the three sensors were then revalidated using the UAV true colour images. Most errors were observed at the edges of burned areas on UAV images (Figure 2), and were undoubtedly linked to the difference in spatial resolution (500-m for MODIS, 30-m for Landsat, 10-m for Sentinel-2, and 5-cm for UAV images). Ground validation and the UAV images also showed that surface fires that do not reach treetops, leaving the treetops green, are not detected by Landsat and Sentinel images.

The Sentinel-2 sensor largely outperformed the other two sensors, with an omission error of 27%, a commission error of 10% and overall better accuracy of 83%. Sentinel-2 also had better spatial (10-m and 20-m) and temporal (5-day) resolution. Moreover, Sentinel-2 images are also free of charge and can use 13 spectral bands. In addition, the probability of having a time series of images even with low cloud cover is greater with Sentinel-2 than with Landsat.

Applying the methods

Based on these results, a monthly analysis of burned areas in the whole country is now made using Sentinel-2 images and the mapping method used in this study; the results are made freely available by the Regional Eastern Africa Fire Management Resource Center (REAFMRC). The centre was established at the Land, Landscape and Development Research Lab at the University of Antananarivo, with the assistance of the Global Fire Monitoring Center (GFMC).

The open-access geoportal of REAFMRC allows fire information to be shared with all stakeholders, from members of the public to policy makers. To support this, REAFMRC organized workshops at the end of 2021 and the beginning of 2022 with the Ministry of Environment and Sustainable Development at the national and regional level for geoportal designers and users from national public and private institutions working on the management of fires and natural resources. One of the first observations following the launch of the geoportal was the reduction of almost 1,000,000 ha in total area burned nationally in 2021 (4,397,342 ha) compared to 2020 (5,380,250 ha). This reduction is linked to the increased presence of the ministry in charge of environment at the local level, and the mobilization of stakeholders in active fire protection and prevention.

Since 1997, satellite remote sensing has increasingly been used to collect information on burned areas. Mapping of burned areas — based on satellite images such as Sentinel-2 — has become an operational tool that facilitates decision making by those responsible for fire management. It provides valuable information for all actors responsible for the management of fire and burned land, through a rapid, accurate and economical estimate of burned areas. Indeed, even if field measurements generally give more accurate estimates of burned areas, they can be difficult to carry out, due to the lack of accessibility of certain burned areas, the considerable time needed to estimate a large burned area, and the significant human and material resources that need to be mobilized.

The technique discussed here makes it possible to quickly locate priority intervention areas for conservation or for planning restoration protocols. In Ankarafantsika National Park, the information provided by satellite data has enabled the park manager to develop, in collaboration with the Ministry of Environment and Sustainable Development of Madagascar, a five-year plan for the restoration of areas affected by fires. The plan will be implemented with local communities, and supported by local environmental organizations and village nurseries that will provide seedlings of forest species for planting. This will not only enrich the park with woody species that are less sensitive to fire and thus reduce the risk of fires in the park, but will also increase local income through the sale of seedlings.

Conclusions

Mapping the extent of fire-affected areas is very important for integrated fire management, especially for stakeholder communication and mobilization, rehabilitation of burned areas, and decision making. Scaling up this type of process allows the development of systematic detection of monthly and annual burned areas, making it possible to calibrate potential fire management responses in open and forested landscapes.

Based on the successful use of satellite mapping data in Madagascar, the REAFMRC geoportal is being extended to cover all East African countries. A first step has been taken: comparing the approach with that of the European Space Agency (which measures burned areas covering all of Africa using Sentinel-2 images, but which is only available for 2019; see Roteta et al. 2019). As of 2023, the geoportal will include the burned areas of a dozen East African countries. The second stage of validation will be carried out with the cooperation of local fire management stakeholders and will be based on field validation.

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