Challenges in the Environmental Enforcement of Small-Scale Illegal Burning

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1. Abstract

In the state of Mato Grosso do Sul, Brazil, a common practice is the burning of residual vegetation left from deforestation, arranged in piles or windrows. IMASUL has the task of identifying unauthorized burnings and taking appropriate administrative sanctions against violators. However, the current remote sensing tools available pose limitations that challenge law enforcement. This paper presents the system created to identify burned areas daily across the entire state, supporting law enforcement in determining the legality of fire incidents. Using a Python script integrated with QGIS, daily FDC data from GOES-R Series ABI is retrieved from Google Earth Engine. The data undergo spatiotemporal aggregation consolidated into a single daily fire event vector layer. Each fire event is then analysed using PlanetScope imagery, and the burned area is manually delineated. Once vectorised, a FAN is generated containing fire data and property identification based on Brazil's Rural Environmental Registry. Between March and August 2025, 938 hotspots were detected, of which 169 (18%) were false positives. The remaining hotspots resulted in 568 FANs, and 45 were selected for on-site inspection. Only one was a false positive, yielding 98% accuracy. 28 inspected FAN corresponded to burning of vegetation residues arranged in windrows or piles, and 25 (89%) lacked authorization or did not comply with the permit conditions. The system represents an important innovation in environmental monitoring and law enforcement in Mato Grosso do Sul. Yet, some limitations remain, such as false positives, cloud cover and imagery availability and lack of omission error quantification.

2. Introduction

Environmental law enforcement agencies face the challenge of acting effectively and in a timely manner to curb actions that violate current legislation. Regarding wildfires and agricultural burning, remote sensing data enables enforcement agents to detect fire hotspots, helping prevent fire spread and allowing the delineation of burned areas for post-incident accountability.

Beyond large-scale fires, in the state of Mato Grosso do Sul, Brazil, some landowners employ fire to eliminate residual vegetation left from deforestation or for pasture clearing. In these cases, biomass is arranged into small piles or linear windrows for burning and later incorporated into the soil. However, Article 58 of Federal Decree No. 6.514/2008 classifies as an environmental infraction the "use fire in agro-pastoral areas without prior authorization from the competent authority or in contravention of the authorization granted", punishable by a fine of BRL 3,000 per hectare or fraction thereof if no permit has been issued (Brasil, 2008).

As the state-level agency responsible for environmental enforcement and management, the Environment Institute of Mato Grosso do Sul (IMASUL, in Portuguese) is tasked with identifying unauthorized burnings, including windrows, piles, native pasture, and wildfires, and take appropriate administrative sanctions against violators. To achieve this, continuous monitoring of the entire 357,125 km² territory of Mato Grosso do Sul is required—an effort made feasible only through remote sensing data. However, the current tools available pose limitations that challenge law enforcement, such as:

- Spatial resolution: Sentinel-2 imagery is commonly used for burn monitoring due to its free access, 5-day revisit time, and shortwave infrared bands ideal for fire detection (ESA, 2021). Yet, with a 10-meter pixel resolution, it fails to capture the smaller-scale piles and windrows used in these burnings.
- Temporal resolution: The Visible Infrared Imaging Radiometer Suite (VIIRS), with a spatial resolution of 375 meters, is typically used for active fire detection (NASA/NOAA, 2023). However, its 12-hour revisit cycle results in significant temporal gaps, given that windrow fires can last from just a few minutes to a few hours, thus often evading detection. Furthermore, remnants of burning may be quickly incorporated into the soil, requiring prompt enforcement action before all physical evidence is lost.

These limitations are not unique to IMASUL; in fact, recent studies confirm that common satellite products lack the accuracy needed to detect small-scale agricultural burns, since these events differ from forest fires in both scale and duration (Hall et al., 2016; Oliveira et al., 2024; Walker, 2024).

The methodology applied in Portugal by Oliveira et al. (2024) proved insufficient to consistently detect most small-scale fires. In the analysed areas, less than 1% of prescribed burn requests were recorded by the sensors. This discrepancy was attributed to factors such as requests without actual fire occurrence, inconsistencies in location or date records, unfavourable atmospheric conditions, insufficient spatial and/or temporal resolution, or a combination of one or more conditions.

Similarly, Walker (2024), in a controlled study conducted in rice fields in India, found high omission rates: MODIS and VIIRS products failed to detect 97% and 100% of agricultural residue burnings, respectively. Even higher-resolution sensors showed significant losses: PlanetScope failed to detect 35% of known events, Sentinel-2 missed 72%, and Landsat 86%.

In Russia, Hall et al. (2016) found similarly high omission errors, ranging from 93% to 97% in summer and 87% in spring. The authors concluded that coarse-resolution sensors such as MODIS, are not suitable for measuring burned areas in croplands. Despite the advantage of daily overpasses, the small spatial scale of agricultural burning requires moderate-resolution sensors. Satellites such as Landsat offer this resolution, but their low revisit frequency (8–16 days) compromises their effectiveness in capturing such rapid and transient processes.

To address these constraints, IMASUL's Geoprocessing Unit (UNIGEO) has developed an automated enforcement system that integrates remote sensing techniques using Geostationary Operational Environmental Satellites (GOES) for fire detection and PlanetScope's very high spatial resolution daily imagery for delineating burned areas. This paper presents the system created to identify burned areas daily across the entire state of Mato Grosso do Sul, supporting law enforcement in determining the legality of fire incidents.

3. Workflow

The GOES-R Series Advanced Baseline Imager (ABI) generates a Fire/Hot Spot Characterization (FDC) product that assigns a fire mask to each pixel, identifying fire categories (GOES-R Algorithm Working Group and GOES-R Program Office, 2018). Although the final product has a spatial resolution of 2 km, it is produced every 10 minutes for the Americas, yielding 144 scenes per day with less than 30 minutes latency—allowing near-real-time detection.

Using a Python script integrated with QGIS, daily fire-pixel layers are retrieved from Google Earth Engine. These pixels undergo spatiotemporal aggregation during fire events to extract information such as the date and time of first detection and the number of scenes the fire mask was assigned to each pixel. The data is then consolidated into a single daily vector layer.

Each fire event is then analysed using PlanetScope imagery, approximately 3.7 m resolution (Planet Team, 2023), provided via a partnership with the Federal Police (Brasil+ Program). Imagery from before and after the fire event is manually interpreted, again in QGIS, to delineate the burned area. Unlike forest fires, which appear as darkened areas, agricultural residue burnings often appear white due to ash accumulation, a feature validated by drone imagery (Figure 1). In cases involving dead vegetation remnants, the linear or dotted patterns characteristic of windrows or piles can be visually distinguished (Figure 2). Once vectorised, A Fire Alert Notification (FAN) is generated for each event, containing fire data and property identification based on Brazil's Rural Environmental Registry (CAR, in Portuguese), which holds data on all rural properties (Figure 3).

Figure 1. Drone imagery illustrating the white coloration of the windrows caused by residual ash left after burning.

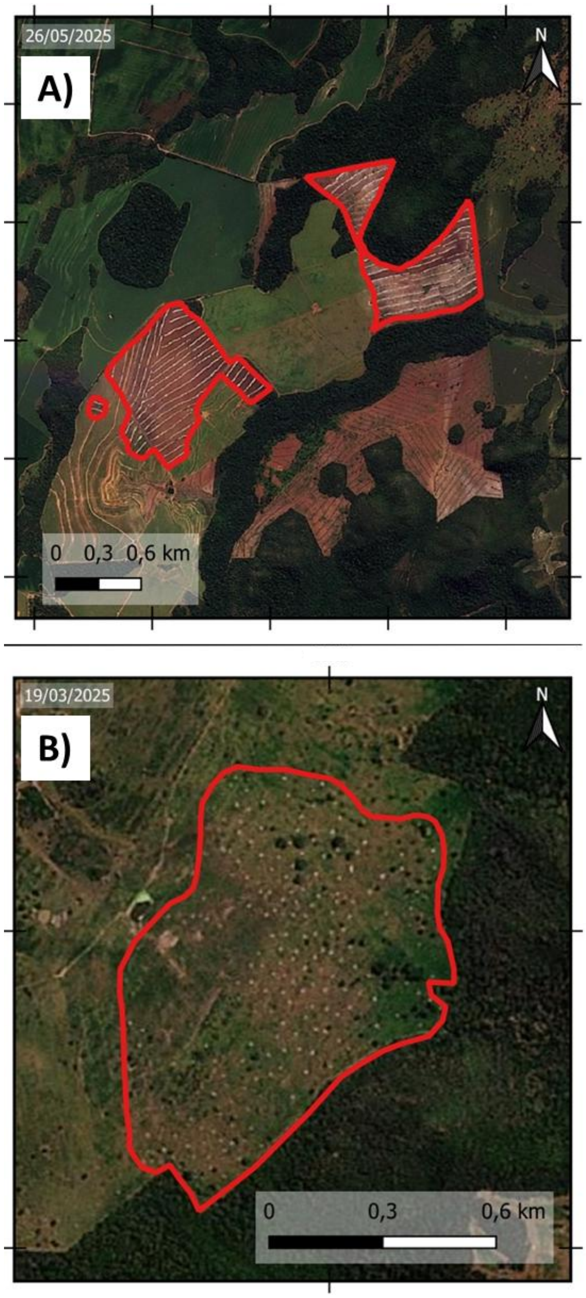

Figure 2. A) Linear pattern of windrows; and B) dotted pattern of piles with burned vegetation residue.


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COMUNICAÇÃO DE ALERTA DE QUEIMADA Nº 217/2025

Informações do Alerta	Informações do Proprietário
Data de Detecção:02/06/2025 Numero de Cenas: 13 Município: Figueirão Interceção Lei 11.428/2006: Sem intersecção Bioma: Cerrado	Número do CAR: [redacted] Proprietário: [redacted] Nome do imóvel: [redacted] C.P.F / C.N.P.J: [redacted] E-mail: [redacted]

EVENTO DE FOGO

Legenda	Informações Cartográficas
Queimadas	Sistema de Coordenadas Geográficas Datum: SIRGAS2000 Fontes: Polígonos de queimada: IMASUL, 2025 GOES-19 FDCF Series ABI Level 2 Fire/Hot Spot Characterization Full Disk 2025-01 Imagem Planet: Daily Imagery 2025-06-01 Daily Imagery 2025-06-05

Campo Grande, 09 de junho de 2025

Figure 3. Fire Alert Notification. Sensitive information was omitted.

Each FAN undergoes a second technical review to check for valid burn authorizations issued by IMASUL. In the absence of such authorization, the burned area is validated and an administrative violation notice is issued, holding the landholder legally accountable, especially when there is evidence of a causal link—i.e., when the burning clearly aligns with common agro-pastoral practices.

For on-site inspections, the UNIGEO team visits each FAN location and conducts drone missions. The imagery collected complements the technical evaluation and, in cases with prior authorization, verifies whether the burned area complies with the terms of the permit.

4. Results

Between March and August 2025, 938 hotspots were detected by GOES FDC. Of these, 169 (18%) were false positives. The remaining 769 hotspots corresponded to 568 FAN, since temporally close but disjointed events on the same property could be aggregated. This represented 720 km² of burned area during the study period. Among the 568 FAN, 45 were selected for on-site inspection corresponding to 0.2 km²; only one was a false positive and yielding 98% accuracy.

Considering the legal aspect of on-site inspected FAN, 28 corresponded to burning of vegetation residues arranged in windrows or piles, while 17 corresponded to fires in agricultural fields. Despite being illegal, agricultural field burnings often lack sufficient evidence to clearly identify the responsible party, limiting administrative sanctions. For vegetation residue cases, 12 cases lacked authorization (with one false positive), while 16 were authorized, of which only two complied with the permit conditions. As a result, 25 (89% of 28 FAN) fines were issued for violations of Federal Decree No. 6.514/2008.

5. Conclusions

Results indicate the proposed workflow is effective for detecting and enforcing regulations against windrow burning, despite the coarse spatial resolution of GOES FDC (2 km). However, some limitations remain:

- False positives: During the evaluation of GOES FDC fire events, false positives were observed, such as fire masks assigned to areas not validated via PlanetScope imagery (Figure 4), or anomalies caused by sunglint in solar farms or water bodies.
- Cloud cover and imagery availability: Despite PlanetScope's near-daily coverage, dense clouds or thick smoke columns can block optical sensors, impairing fire detection and burned area mapping—specially during the rainy season or intense fire episodes. Given the short duration of windrow burning, even a few consecutive cloudy days can result in missed detections if the post-burn residues are rapidly incorporated into the soil.
- Lack of omission error quantification: Since the workflow begins with GOES FDC data, fire events not detected by this product are not analysed by technicians, making it difficult to quantify undetected windrow burning events.

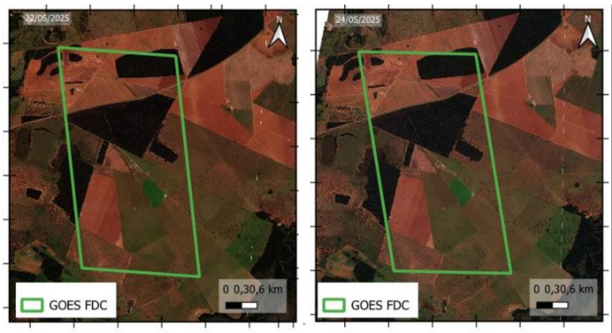

Figure 4. Fire event detected by GOES FDC, but it could not be validated using PlanetScope imagery. Detection date: 23 May 2025, 10 scenes.

Despite these constraints, the system represents an important innovation in environmental law enforcement in Mato Grosso do Sul, which previously lacked systematic fire monitoring. The application of advanced remote sensing techniques is crucial not only for improving enforcement effectiveness but also to reinforce the credibility of public institutions responsible for protecting natural resources. Establishing a robust environmental monitoring system directly contributes to law enforcement and fosters accountability, promoting sustainable land use and aligning environmental protection with socioeconomic development.

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