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Fire Analysis in Grasslands using Remote Sensing: A Systematic Review

Sensoriamento Remoto Aplicado à Análise de Fogo em Formações Campestres: Uma Revisão Sistemática

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Abstract: Assessing the fire impact on grasslands requires understanding how the environmental and anthropic relationships affect the landscape dynamics. This study carries out a systematic literature review to understand fire behavior in grasslands through remote sensing techniques. To this end, the Scopus data was used employing the PRISMA method with the cluster mapping aid. Initially, 7,881 articles were found in the literature. The methodological steps applied to them resulted in 67 articles, which were used in the analysis. The results indicated increased interest in research in the area, with Brazil having the second-highest number of studies. Several publications utilized orbital images. However, there has been recent growth in the use of images obtained from UAV-mounted sensors. In addition to the NDVI and EVI indices, other indices have been used recently for analyzing burn severity and the vegetation recovery process. These subjects are primarily related to integrated fire management, which must consider conserving biodiversity and human use to reduce the fire's intensity and severity to make them more controllable and reduce their negative impacts. Therefore, remote sensing is essential for understanding the fire spatial-temporal behavior and, consequently, serves as a scientific aid to help decision-making in burn prescription cases, considering the ecosystems maintenance and the better grassland use.
Keywords: Burns. Spectral indices. Grasses. NBR. VOSviewer.

Resumo: Avaliar o impacto do fogo em formações campestres requer uma compreensão das relações ambientais e antrópicas sobre a dinâmica da paisagem. Este estudo faz uma revisão da literatura para entender o comportamento do fogo em formações campestres por meio de técnicas de sensoriamento remoto. Para isso foi utilizada a base de dados da Scopus por meio do método PRISMA com o auxílio de mapeamento de *clusters*. Primeiramente, foram encontrados 7.881 artigos na literatura cientifica, onde foram aplicados os passos metodológicos, resultando em 67 artigos, os quais foram utilizados na análise. Os resultados apontam uma tendência de crescimento de pesquisas com a temática, sendo o Brasil o segundo país com maior contribuição ao resultado. Grande parte das publicações utilizaram imagens orbitais, porém há um crescimento recente da utilização de imagens obtidas por sensores acoplados a VANT's. Além dos índices espectrais NDVI e EVI, observa-se a recente a utilização de outros índices para analisar a severidade das queimadas e o processo de recuperação da vegetação. Estes temas são principalmente relacionados com o manejo integrado de fogo, que deve levar em consideração a conservação da biodiversidade e uso antrópico com o objetivo de reduzir a intensidade e severidade do fogo, para torná-lo mais controlável e reduzir seus impactos negativos. Portanto, o sensoriamento é essencial para entender o comportamento espaço-temporal do fogo e consequentemente servir de subsídio científico para auxiliar a tomada de decisão em casos de prescrição de queimadas levando em consideração a manutenção dos serviços ecossistêmicos e a utilização destas formações campestres.
Palavras-chave: Queimadas. Índices espectrais. Gramíneas. NBR. VOSviewer.

1 INTRODUCTION

Grasslands are an important ecosystem component, covering more than 30% of the globe (SHOKO; MUTANGA; DUBE, 2016) and providing essential ecosystem services, such as vegetal and animal biodiversity maintenance, soil erosion control, and carbon cycle regulation (WANG *et al.*, 2019). Nonetheless, this vegetation formation is highly susceptible to fragmentation, and the remnants are vulnerable to land use, bad management practices, and climate variability (HE; YANG; GUO, 2020).

Beyond the factors mentioned above, it can be said that fire is one of the primary ecological process dynamic disturbances in various ecosystems, including grasslands (HOFFMANN *et al.*, 2012), making them a critical transformation agent for terrestrial system behavior (BOND; WOODWARD; MIDGLEY, 2005).

Although some of these ecosystem changes are desirable from an ecological perspective, the destructive consequences are generally considered undesirable and require greater observation (SZPAKOWSKI; JENSEN, 2019). So, the grassland fire's spatio-temporal incidence patterns need to be assessed to understand better the environmental relationships and the anthropic factors that influence landscape dynamics. Therefore, remote sensing constitutes an essential data source to analyze the burn's effect on multiple spatial, temporal, and spectral scales (ABDOLLAHI et al., 2018; CHUVIECO et al., 2019; GIGLIO et al., 2010).

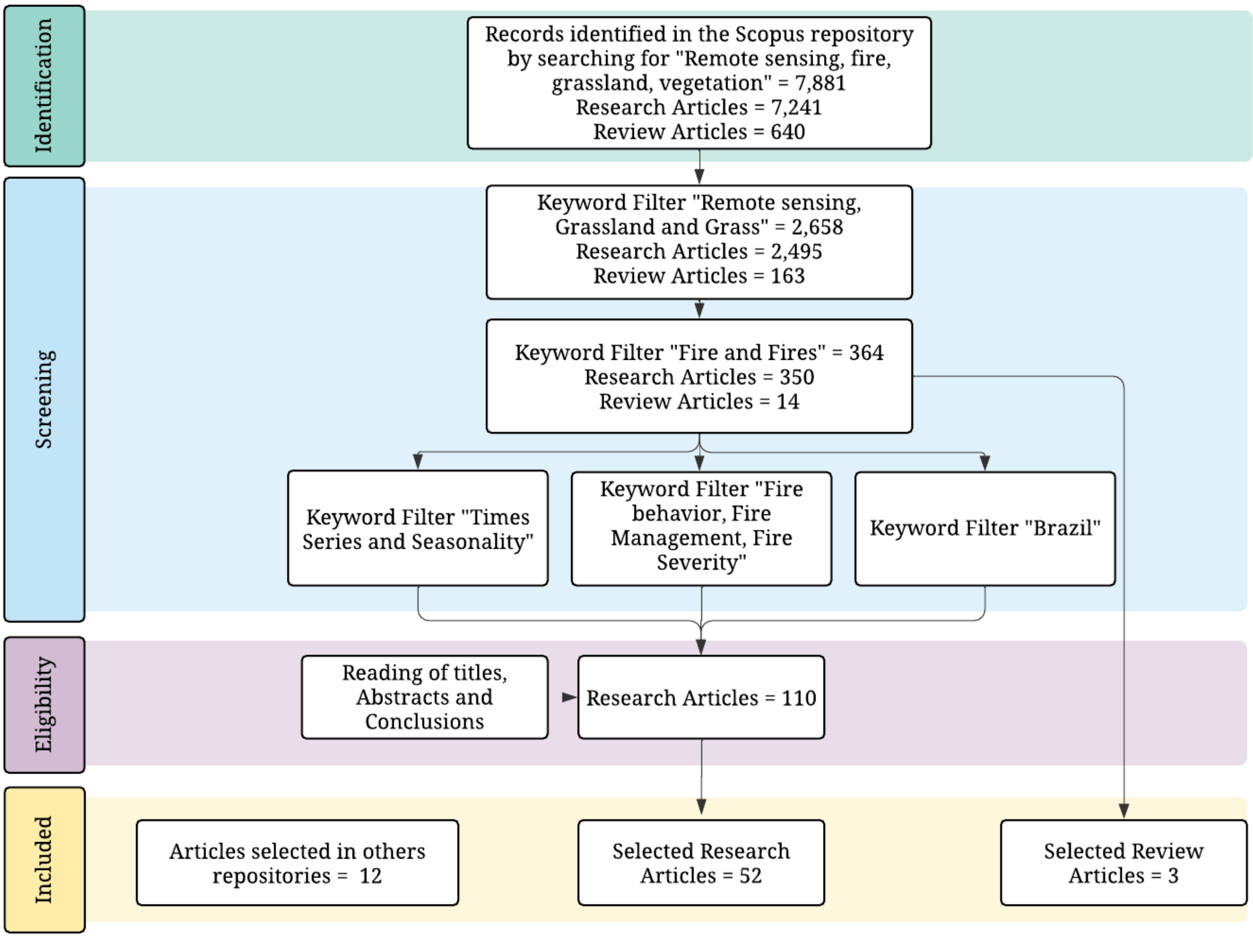
Once several studies apply remote sensing to research fire, a comprehensive review of these investigations is needed to understand the investigation standards in the area. Thus, systematic reviews applied to geoscience have been undertaken more often, as remote sensing has become a complementary information source and, in many cases, the only viable (SHEFFIELD *et al.*, 2018). Systematic reviews are helpful because they use a method that visualizes quantitative information about a research domain, allowing the researcher to gain insights into specific aspects of the subject studied (SU; LEE, 2010).

One of the most used methodologies for this is the Preferred Report Items for Systematic Revision and Meta-analysis (PRISMA) which was elaborated to address various conceptual and practical advances in the systematic review science (MOHER *et al.*, 2009). The PRISMA was previously used for remote sensing reviews, for example, to analyze large-scale data sets and environmental monitoring (TAMIMINIA *et al.*, 2020), in urban scenario simulations in land use and cover change models (WANG; MURAYAMA; MORIMOTO, 2021), in machine-learning methods (SHEYKHMOUSA *et al.*, 2020), and UAV data processing (ESKANDARI; MAHDIANPARI; MOHAMMADIMANESH, 2020). In addition to PRISMA, this study also used VOSviewer, a bibliometric mapping application capable of providing a broad scientific literature view. Our main goal is to do a systematic literature review describing the state of the art in fire behavior and use in grasslands via remote sensing techniques.

2 METHODOLOGY

For this study, a systematic review was done, gathering the primary publications, influential authors, journals, countries, and organizations to identify emerging research directions regarding remote sensing techniques applied to understand the fire in grasslands published through March 2021. It's important to highlight that no review study about this subject was found before in the literature, thus suggesting a need to synthesize this knowledge. This research used the PRISMA method, divided into four phases labeled identification, selection, eligibility, and inclusion, presented in Figure 1 and described in the items below.

Figure 1 – Flowchart of the PRISMA methodology research phases.



Source: The authors (2021).

2.1 Step 1: Identification

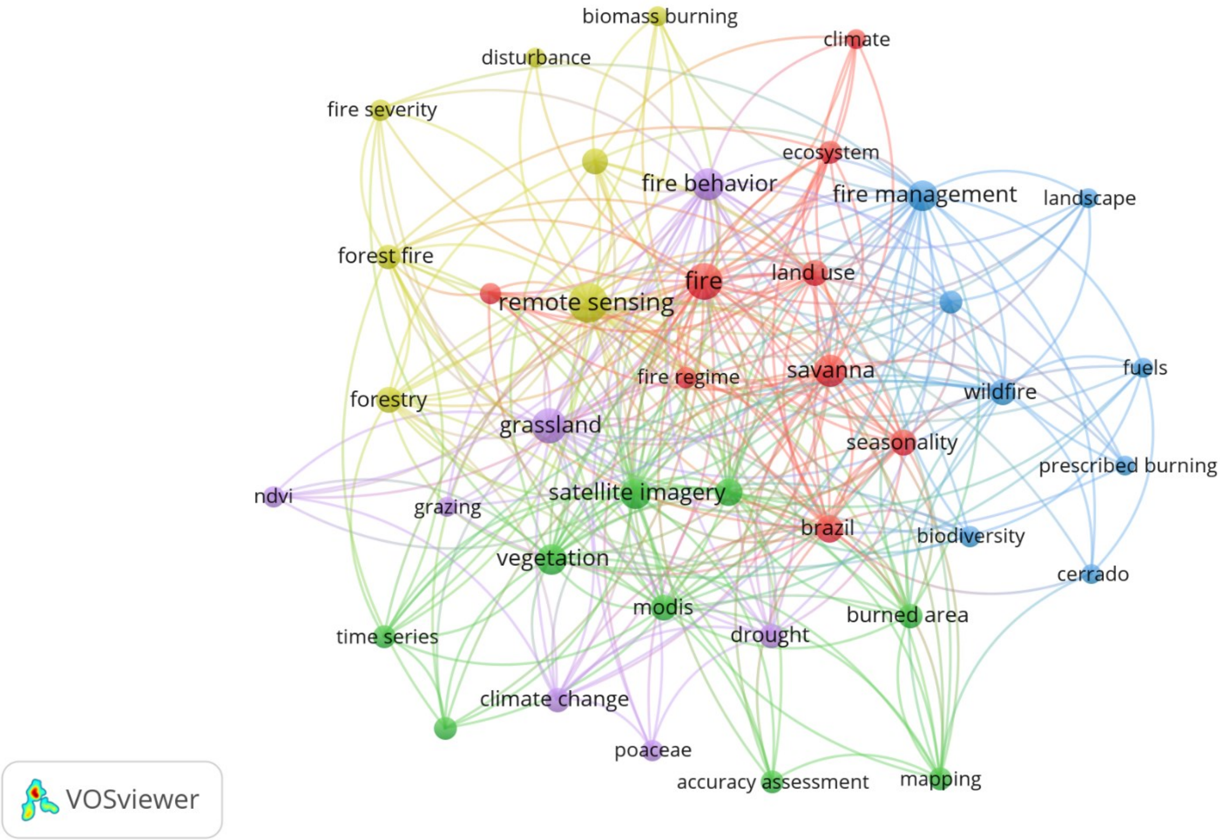
In the identification phase, the approach adopted for consulting the literature consisted of a search for words that best represented the subject of interest, namely: ”remote sensing,” “fire,” “vegetation,” and “grassland.” The keywords were used to filter the Scopus library (www.scopus.com), one of the most extensive abstracts and citation databases in the world's peer-reviewed research literature, covering over 5,000 international journals (VIANA et al., 2017). Only documents published as research and review articles in Portuguese, English, or Spanish were chosen. In this first step, 7,881 articles were found.

2.2 Step 2: Selection

The articles identified in the first step were extracted for the selection step and filtered using the keywords “remote sensing,” “grassland,” and “grass” to select studies with an emphasis on remote sensing applied to grasslands resulting in 2,658 articles. Then, they were passed through a new filter, where the keywords “fire” and “fires” were used to understand how the fire occurrence in this vegetation was being addressed, resulting in 364 articles.

Of these, 14 articles were directly chosen for the eligibility step. Next, the other 350 articles were submitted for keyword and thematic axis identification via the VOSviewer software (Figure 2), which creates maps based on network data, forming clusters. In the figure, the item’s weighting determines the circle size, the group to which the keyword belongs, and the cluster’s color. The lines represent links or associations, while the distance indicates the strength of the relationship between the occurring keywords (ECK; WALTMAN, 2020; WALTMAN; VAN ECK, 2013).

Figure 2 –Keywords cluster network analysis of the 364 articles found in the PRISMA method selection step.



Source: The authors (2021).

The following filter choice was based on the connection between words in the cluster map (Figure 2) and their relationship to this article's subject. The words selected were:

a) “time series” and “seasonality” = were chosen to understand the temporal occurrence and inter-annual fire behavior over the years and the intra-annual fire between seasons.
b) “fire behavior,” “fire management,” and “fire severity” = were selected to gain insight into the leading spectral indices and methodologies utilized to monitor the fire intensity and factors that contribute to its occurrence related to vegetation recovery after burn.
c) “Brazil” = was chosen to limit the studies to ones addressing the fire use in grasslands fields in Brazil to verify how the subject has come to be applied in the country.

The above filters applied in this selection step resulted in 110 articles analyzed in the next stage.

2.3 Step 3: Eligibility

In the eligibility step, the titles, abstracts, and conclusions were read to select only the articles whose content was related to fire use and behavior in grasslands throughout remote sensing.

2.4 Step 4: Inclusion and data analysis

In this last step, inclusion, 52 research and three review articles were chosen. In addition, 12 references cited by the articles read and found in other databases than Scopus were added to the analysis. Thus, 67 articles were included in this systematic review and had their information cataloged (Table 1). Additionally, VOSviewer was used to classify the article’s relevance and their regional and global contribution in this final step. In addition, several pieces of information, such as the satellites, sensors, and spectral indices most employed in the articles, were cataloged to identify the research trends.

Table 1 – Parameters cataloged during the systematic review.

Parameter	Description
Type	Article type (study or review)
Citations	Number of article citations relative to its publication date
Name	Name of study/review
Author	Author(s) name(s)
Journal	Name of the journal where the study was published
Publication year	Year article was published
Satellites and sensors	Name of satellite(s) and/or sensor(s) used
Spectral indices	Number and name of Indice(s) used

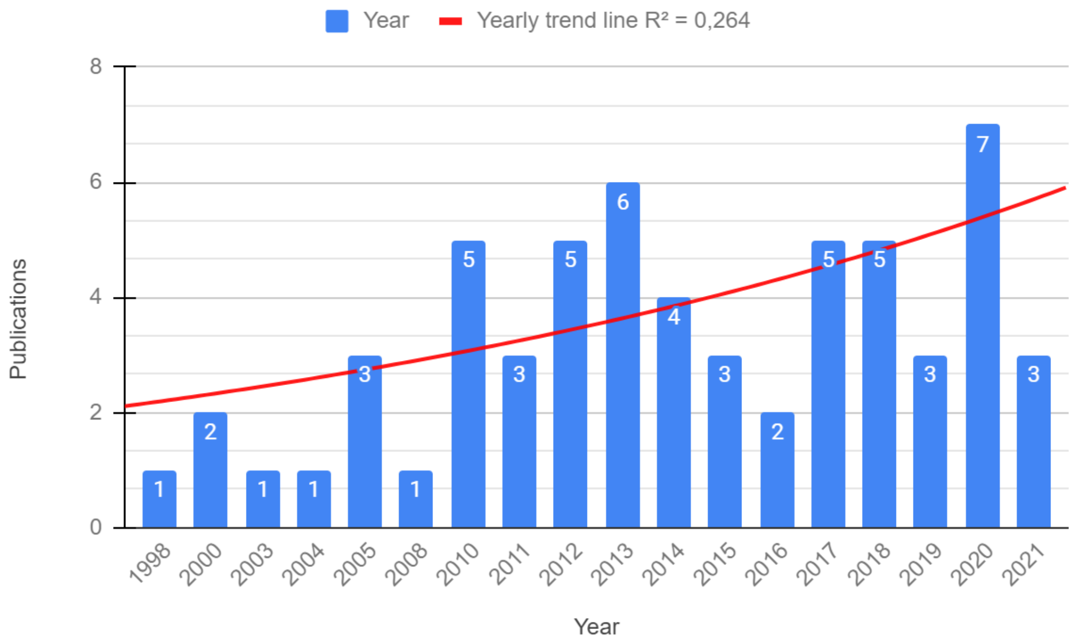
Source: The authors (2021).

3 RESULTS AND DISCUSSION

3.1 Analysis of scientific production and its relevance

Of the 7,893 publications found, after applying the filters presented in Figure 1, 67 articles remained; the complete list is shown in the (supplementary material). These articles were analyzed more deeply in the systematic review. The reviewed articles were published between 1998 and the first trimester of 2021 (Figure 3).

Figure 3 – Distribution of publications from January 1998 to March 2021.



Source: The authors (2021).

The publications' growth over the period can be seen, particularly starting in 2010. Most noteworthy are the years 2013 and 2020, with six and seven scientific articles published, respectively, and 2021 which could easily surpass these years since it already presented three articles published in the first trimester.

In addition, each article's citations were counted, which according to GARNER et al. (2018), is the measure commonly adopted to assess the publication's academic influence. However, the following equation was used to normalize the citations number over time and define the reviewed article's influence degree: Influence = Citations / (Base year – publication year). The publications were ranked from most to least influential, and the six highest are presented in (Table 2).

Table 2 – Most influential articles.

Author	Title	Year	Journal	Influence
CHUVIECO *et al.*, 2019	*Historical background and current developments for mapping burned area from satellite Earth observation*	2019	Remote Sensing of Environment	34.0
STAVER; ARCHIBALD; LEVIN, 2011	*Tree cover in sub-Saharan Africa: Rainfall and fire constrain forest and savanna as alternative stable states*	2011	Ecology	29.0
BOWMAN *et al.*, 2020	*Vegetation fires in the Anthropocene*	2020	Nature	24.0
(ROY *et al.*, 2005)	*Prototyping a global algorithm for systematic fire-affected area mapping using MODIS time series data*	2005	Remote Sensing of Environment	22.8
YEBRA *et al.*, 2013	*A global review of remote sensing of live fuel moisture content for fire danger assessment: Moving towards operational products*	2014	Remote Sensing of Environment	16.4
ALVARADO *et al.*, 2017	*Drivers of fire occurrence in a mountainous Brazilian cerrado savanna: Tracking long-term fire regimes using remote sensing*	2017	Ecological Indicators	11.0

Source: The authors (2021).

Many of the most influential articles are reviews and have been available for at least ten years, with only two of them having been published in the last three years. One common characteristic among them is the study's area scale, which was regional or global. As was noted by ROY et al. (2005), one of the satellite remote sensing advantages is to be capable of monitoring the vegetation burn on a broader scale. Moreover, it is worth highlighting the Chuvieco et al. (2019) study, which reviews remote sensing applied to fires over the last 40 years. In this study, the authors synthesized the physical basis for detecting burned areas, the historical trends of satellite sensors used to monitor them, and the identification of potential opportunities for improving burn area detection.

3.2 Analysis of satellites and sensors used

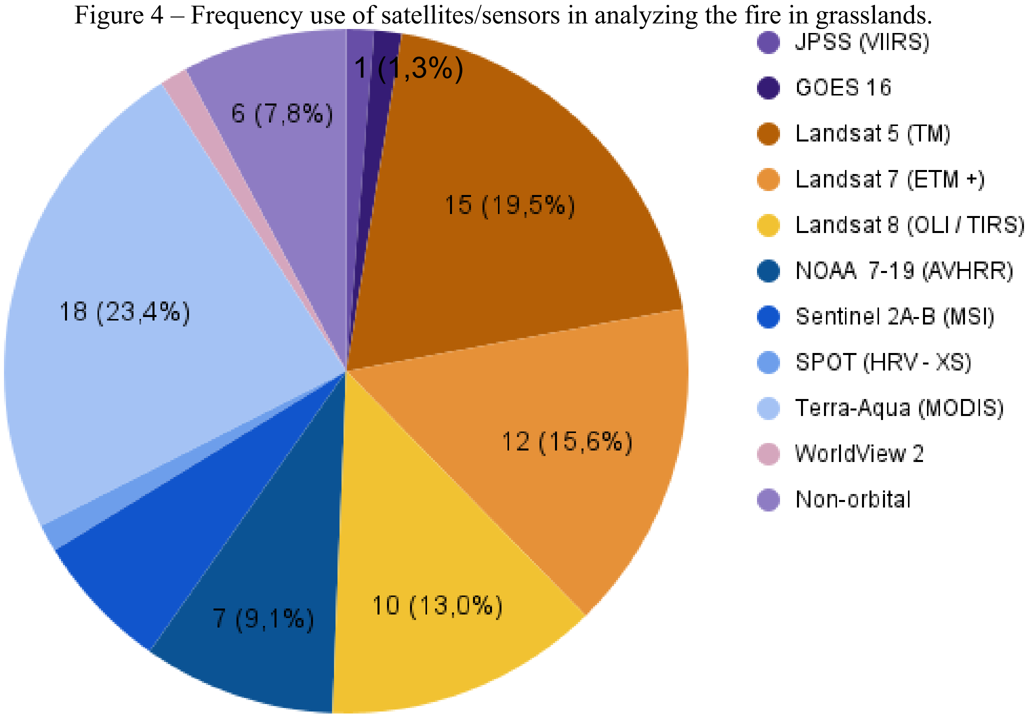
This study found many sensors and platforms used in various stages to assess the grassland fires behavior via remote sensing data. A list of the satellites/sensor's names, operators, and temporal and spatial resolutions is described in (Table 3), while the frequency with which they were utilized is presented in Figure 4.

Table 3 – Satellites and sensors found in the systematic review.

Satellite (sensor)	Operator	Temporal resolution	Spatial resolution	Publications
JPSS (VIIRS)	NOAA	1 - 2 days	375-750 m	1
GOES - 16	NOAA / NASA	Geostationary	1 - 4 km	1
Landsat 5 (TM)	NASA / USGS	16 days	30 - 120 m	15
Landsat 7 (ETM +)	NASA / USGS	16 days	15 - 30 - 60 m	12
Landsat 8 (OLI/ TIRS)	NASA / USGS	17 days	OLI: 15/30 m TIRS: 100 m	10
NOAA-7-19 (AVHRR)	NOAA	1 - 2 days	1100 m	7
Sentinel 2A-B (MSI)	ESA	5 days	10 - 20 - 60 m	5
SPOT (HRV - XS)	CNES	26 days	2.5 -20 m	1
Terra-Aqua (MODIS)	NASA	1 - 2 days	250 m	18
WorldView 2	Digitalglobe	1.1 - 3.7 days	0.3 - 2 m	1

Source: The authors (2021).

Figure 4 – Frequency use of satellites/sensors in analyzing the fire in grasslands.



Source: The authors (2021).

Although the majority of studies, around 48%, used the Landsat series (ALVARADO; SILVA; ARCHIBALD, 2018; PEREIRA JR. et al., 2014; WILLIAMSON; MURPHY; BOWMAN, 2014), optical images with lower spatial resolution, such as those obtained by MODIS and AVHRR, represent approximately 23% and 9% each. It is also worth noting that only one study used hyperspatial orbital imagery from WorldView (FERNÁNDEZ-GUISURAGA; CALVO; SUÁREZ-SEOANE, 2020). Meanwhile, satellites with high spatial resolutions, such as Sentinel and SPOT, were used in approximately 8% of the reviewed articles.

Regarding orbital platforms, there are several alternatives, such as those offered by the NASA/USGS program. For example, Landsat 7 and 8 are currently in operation, while Landsat 9 was launched in the second half of 2021 to continue obtaining Earth's remote sensing images. All the satellites, operated by the United States Geological Survey (USGS), cover the Earth every 16 days, collecting data in various frequency bands, such as the visible (V), near-infrared (NIR), short-wavelength infrared (SWIR), and thermal infrared (TI), from 30 to 100 meters of special resolution (USGS, 2021). One of the Landsat satellite's strengths is the coverage cycle consistency along the time (ALVARADO; SILVA; ARCHIBALD, 2018; GOODWIN; COLLETT, 2014). Currently, with three satellites in operation, it should go down to eight days, providing essential data for temporal series analysis.

On the other hand, the Moderate-Resolution Imaging Spectroradiometer (MODIS) onboard the satellites Terra and Aqua, also administered by NASA, have a lower spatial resolution but a higher temporal resolution with revisits every 1-2 days. This sensor provides high radiometric sensitivity, gathering data in 36 frequency bands from 0.4 to 14.4 µm, with a spatial resolution varying from 250 m to 1 km. It plays a vital role in developing interactive, global, validated Earth system models capable of predicting global changes with enough precision to help policymakers protect the environment and make decisions (NASA, 2021).

MODIS and Landsat images were likely used more often because of their long history and are freely available. With their higher revisits time, Aqua and Terra allow detection of drastic changes in Earth and any deviation from the expected ecosystem healthy state (SLINGSBY *et al.*, 2020), consequently giving relevant information that serves to bolster fire use understanding (CHEN et al., 2017).

However, it is worth highlighting that some of MODIS's disadvantages are its low spatial resolution, making it impossible to detect small fires. One solution for this problem would be to use Sentinel-2 data, a more-recently-launched satellite in 2015, which carries an optical instrument with 13 frequency bands, a spatial resolution between 10 and 60 meters, and five days revisit time with two satellites, Sentinel 2A, and 2B currently in operation (ESA, 2021).

Due to the visible-near infrared and SWIR bands and their refined spatial resolution, the optical data from Sentinel-2 presents better performance when applied to vegetation than other sensors. The isolated bands and vegetation indices combined from Sentinel-2's images have the potential and robustness to estimate the grasslands biomass. They have demonstrated superior performance in grass species discrimination compared to Landsat and Worldview (GUERINI FILHO; KUPLICH; QUADROS, 2020).

Non-orbital data sources represent approximately 8% of the remote sensor used in our reviewed articles. Most of these studies were published recently, in the last five years. The data was obtained from UAVs presenting high spatial and temporal resolution images as one of their main advantages. In addition to acquiring near real-time data, new remote sensing information sources are arising, such as multispectral and hyperspectral sensors (HAKALA et al., 2018; RAMPANT; ZDUNIC; BURROWS, 2019, CRUSIOL et al., 2020).

3.3 Spectral Index Analysis

Analyzing the grassland's spectral reflectances in different phytosociological compositions and climatic variations may help to classify and discriminate them (YANG *et al.*, 1998). Using image analysis techniques, detailed vegetation characteristics can be identified, such as the annual cycle and phenological variations, demonstrating the remote sensing potential.

The interaction process between visible spectrum electromagnetic radiation and a leaf depends on chemical factors such as photosynthesizing pigments and water and structural elements such as leaf tissue organization, which can be analyzed using radiation absorption, transmission, and reflection (FLORENZANO, 2011).

Based on the vegetation spectral signature, mathematical models represented by several indices can be obtained. These are developed to evaluate the vegetation cover and associate the spectral signature to quantitative and qualitative parameters in the field (GUERINI FILHO; KUPLICH; QUADROS, 2020).

The indices function as vegetation growth and vigor indicators. They can be used to diagnose various biophysical parameters with which they highly correlate, including leaf area, biomass, soil-covered percentage, photosynthetic activity, and vegetation productivity. In this systematic review, the most-used spectral indices in the reviewed articles were organized and are presented in (Table 4).

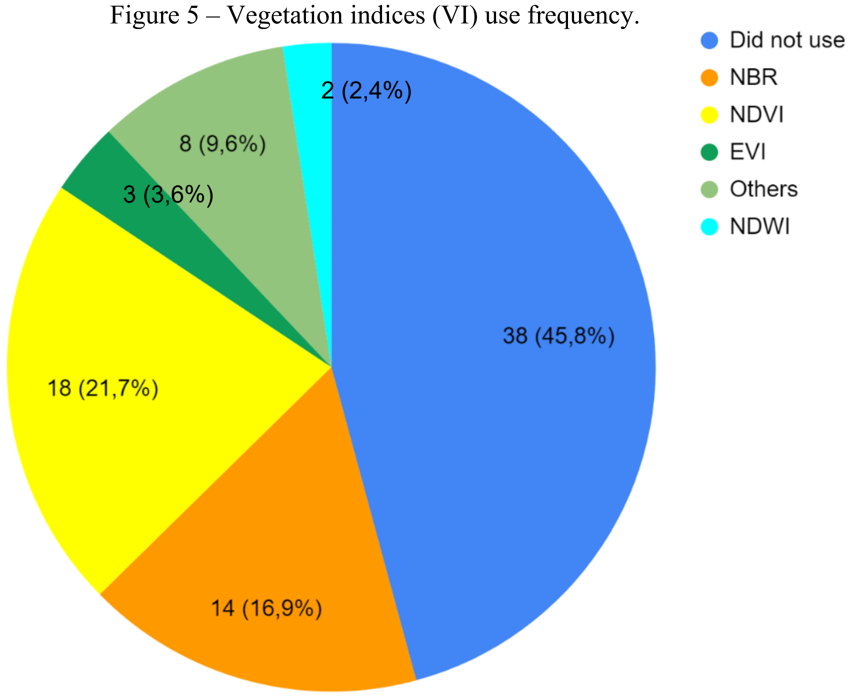
Table 4 – Principal spectral indices used in the remote sensing studies for analyzing fire use in field vegetation.

Index	Equation	Author
Normalized Difference Vegetation Index (NDVI)	$NDVI = \frac{NIR - Red}{NIR + Red}$	ROUSE et al., 1973
Enhanced Vegetation Index (EVI)	$EVI = G * \frac{(NIR - Red)}{(NIR + C1 * Red - C2 * Blue + 1)}$	HUETE et al., 1997
Soil-Adjusted Vegetation Index (SAVI)	$SAVI = \frac{(NIR - Red)}{(NIR + Red + L) * (1 + L)}$	HUETE, 1988
Normalized Difference Water Index (NDWI)	$NDWI = \frac{\rho(0.86\mu m) - \rho(1.24\mu m)}{\rho(0.86\mu m) + \rho(1.24\mu m)}$	GAO, 1996
Normalized Burn Ratio (NBR)	$NBR = \frac{NIR - SWIR}{NIR + SWIR}$ $dNBR = NBR_{pre-fire} - NBR_{pos-fire}$	KEY; BENSON, 2006

Source: The authors (2021).

This study discovered that more than half of the articles used vegetation indices (VI) to investigate the fire and its interactions with vegetation (Figure 5). A general VIs characteristic is the data reduction volume to be analyzed by estimates of structural and physiological biophysical data extractable from vegetation.

Figure 5 – Vegetation indices (VI) use frequency.



Source: The authors (2021).

Among the best-known indices, applied via the equation proposed by Rouse et al. (1973), NDVI is obtained by normalizing the reflectances in the NIR and red (R) bands to values that lie between -1 and +1. However, for vegetation, these values varied from 0 to +1. NDVI was the most prominent VI and was used in approximately 22% of the articles reviewed and applied in study areas on all continents. For example, YANG et al. (1998) showed that time-series NDVI data could measure grassland performance under seasonal climatic influences.

Some remote sensing grassland challenges are soil, atmosphere effects, and variations in vegetation density. Spectral indices that take these interference sources into account, such as SAVI and EVI, are a solution for mitigating the NDVI limitations (ALVARADO, S.T. *et al.*, 2017).

Hence, a VI such as SAVI involves only the constant "L" addition to the NDVI denominator equation, where L takes values accordingly to the vegetation density: very low (L = 1), intermediate (L = 0.5), or very high (L = 0.25) (HUETE, 1998). For EVI, in addition to the SAVI soil increment, there are the constants C1 and C2, which are functions that use the blue band to correct the aerosol influences on the red band, with the most used values being G = 2.5, C1 = 6.0, and C2 = 7.5 (HUETE et al., 1997). EVI represented around 4% of VI in the articles reviewed. The index has one "ready to use" version available as a time series from MOD13Q1, produced from MODIS data. The MODIS EVI index synthesizes vegetation data every 16 days and first became available in February 2000, with a 250 m spatial resolution (ALVARADO, S.T. *et al.*, 2017).

Thus, spectral indices have been applied in several grasslands fire science and management aspects, including fuel estimation, fire risk mapping, burn severity assessment, fire detection, and fire propagation rate estimation (DÍAZ-DELGADO; LLORET; PONS, 2003; WANG, J. *et al.*, 2019; WULDER *et al.*, 2020). Recently, among the most-used indices is NBR, a ratio of NIR and SWIR regions. It was developed to identify post-fire burn areas and quantitatively measure their severity (KEY; BENSON, 2006).

NBR is primarily sensitive to chlorophyll and the water content of soil and vegetation. These characteristics associated with land use, fire history, topography, climate, and field data need to be evaluated together to establish effective strategies for managing protected areas and prescribed burns in the case of fire management (FRANKE et al., 2018). NBR represents around 17% of the VIs used. However, it is usually used with other indices in many studies and is notoriously applied to model the vegetation response capacity after fire perturbation events (ADAGBASA; ADELABU; OKELLO, 2020a).

Also, using SWIR frequencies, NDWI corresponds to approximately 2% of the VIs in the articles reviewed. Since NDWI uses vegetation water spectral ranges, it can minimize the confusion between burned, wetland, and agricultural bare soil areas and also estimate dry biomass (XU *et al.*, 2014). These effects imply a highly variable vegetation response that depends on different post-fire vegetation regeneration strategies, such as massive seed production and regrowth (ADAGBASA; ADELABU; OKELLO, 2020).

Other VIs were used in around 9% of the articles reviewed. They were presented together with NDVI or NBR, or other meteorological and soil indices. Moreover, it is worth stressing that geomorphometric data combined with vegetation response can provide information about burn area severity (EVANGELIDES; NOBAJAS, 2020). In addition, the interactions between fire severity and plant regeneration and topographic, climatic, and vegetation factors aren't still well understood.

3.4 Regional and global contribution

Among the review papers' author's peer groups and home countries (Figure 6), around ten countries are noteworthy (Table 5). The largest contributors are the United States, with about 25% of the articles and 34% citations, followed by Brazil with 16% and 7%, respectively. Although Brazil has nearly two-thirds the number of articles that the United States has, its strength is close to half the United States, probably due to the connections between the American authors. On the other hand, even though Spain has fewer publications than Brazil, it has an almost equivalent strength, which may be because it has over 300 more citations.

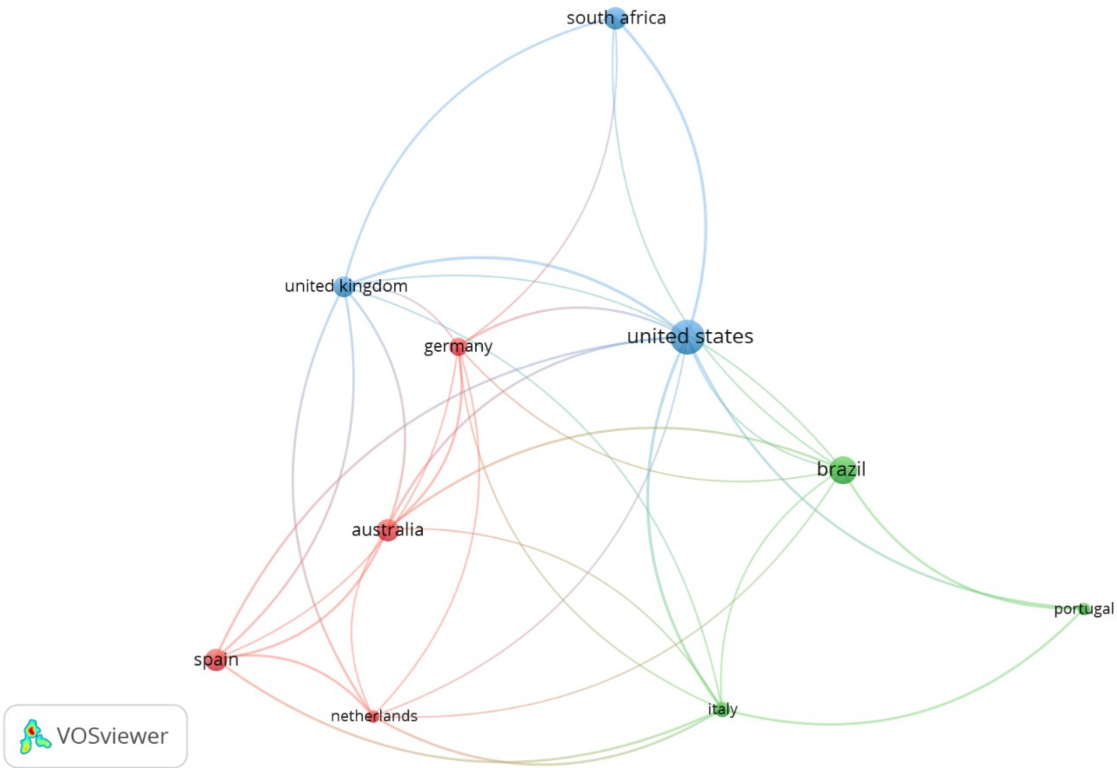
Table 5 – Originating countries of the reviewed articles author's institutions.

Country	Articles	Citations	Strength
United States	22	1567	19
Brazil	14	319	10
Spain	10	620	11
South Africa	9	500	7
Australia	9	358	12
United Kingdom	8	686	14
Germany	6	149	10
Italy	5	246	13
Netherlands	3	139	10
Portugal	3	64	6

Source: The authors (2021).

However, if the European publications are added, they constitute around 35% of the articles and 40% of citations, while publications from the Americas represent 40% and 41%, respectively. Finally, Africa and Oceania are represented by only one country each. South Africa has 10% of the articles and 11% of the citations, and Australia, has 10% and 8%, respectively. In this case, while the two countries have the same number of articles, they present different citations, with Australia's count being almost double that of South Africa's and grouped in other clusters (Figure 6).

Figure 6 – Cluster network analysis of the principal connections between the countries of the articles reviewed.



Source: The authors (2021).

The connection network between authors has ten nodes, three clusters, and 34 links. Each link has a strength, represented by a positive number, where the higher the value, the stronger the connection. The strength may, for example, indicate the references citation's number the two publications have in common, in the case of shared bibliographic links, the publications number of which the researchers are coauthors, or the publications number in which two terms occur together (ECK; WALTMAN, 2020).

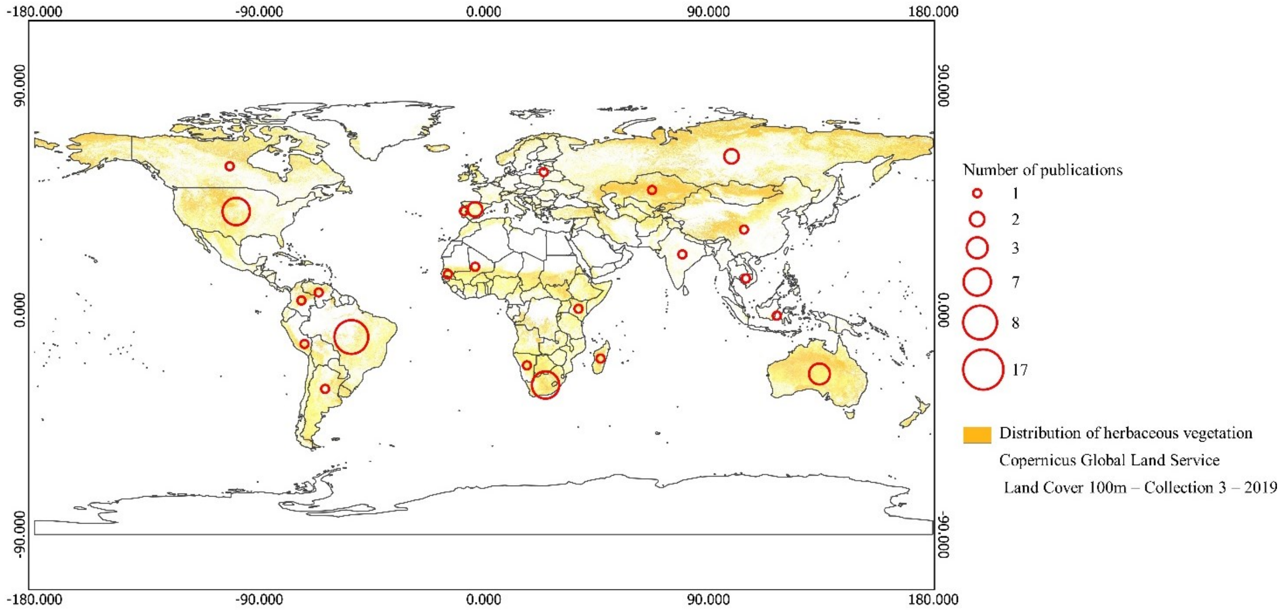
Upon analyzing the publications' originating countries, the study areas often do not correspond to the same countries. Therefore, to spatialize the grassland vegetation and fire distributions worldwide, we used the Copernicus Global Land Service: Land Cover 100m: collection 3 - 2019 (BUCHHORN *et al.*, 2020) and hotspots obtained by MODIS, collection 6.1, also for 2019 (NADA, 2022). The herbaceous vegetation class distribution combined with the reviewed article's study areas is shown in Figure 7 and Table 6.

Table 6 – Locations of study areas and article number by country.

Study area	# of articles
Brazil	17
South Africa	8
United States	8
Australia	7
Spain	3
Russia	3
Argentina	2
Cambodia	2
Canada	2
Colombia	2
India	2
China	1
Indonesia	1
Kazakhstan	1
Lithuania	1
Mali	1
Namibia	1
Peru	1
Kenya	1
Senegal	1
Sub-Saharan Africa	1
Venezuela	1
Madagascar	1
Portugal	1

Source: The authors (2021).

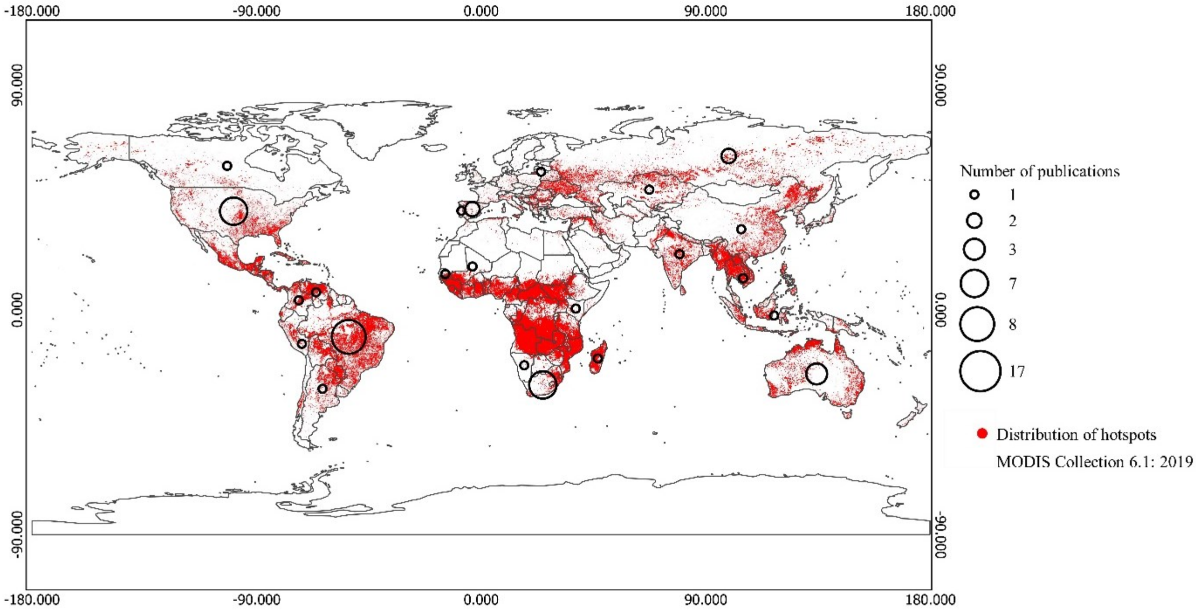
Figure 7 – Geographic distribution of grassland formations worldwide and concentration of reviewed articles by country.



Source: The authors (2021).

Ecosystems such as savanna/Cerrado and steppe/prairies/plains are the most common grassland vegetation type in most reviewed studies' countries. In regions such as the Brazilian Cerrado, fire probability estimation studies are recurrent as they help prevent big fires (ALVARADO et al., 2017; FRANKE et al., 2018; PEREIRA et al., 2014; SANTOS et al., 2020). This highlights that regions with intermediate primary productivity levels, such as tropical savannas, burn more often (Figure 8) due primarily to the fuel abundance, consequently raising interest in the issue (BOWMAN *et al.*, 2020).

Figure 8 – Hotspots geographic distribution in 2019 and concentration of reviewed articles by country.



Source: The authors (2021).

There are grassland vegetation remnants in the Amazon region where savanna phytophysiognomies predominate (DIPAOLO, 2020). As a decentralized remnant of the Cerrado biome, monitoring fire activity is essential to understanding the ecological processes, human impacts, and aspects connected to seasonality and patterns in the fire incidence (ALVES; PÉREZ-CABELLO, 2017).

In southern Brazil, a different situation is found, with mosaic formations of Araucaria (Brazilian pine) forests and Campos (grasslands), where it is hypothesized that grassland maintenance is anthropogenic in origin, since the landscape dynamics show the initial Araucaria expansion into Campos fields after grazing and fire no longer being used (OLIVEIRA; PILLAR, 2004).

3.5 Journals Analysis

The publications journal's co-citation analysis sought to discover which research contexts the remote sensing subject applied to understanding fire use in grassland vegetation was addressed. In this study, scientific articles published in 32 scientific journals were founded and classified. The journals were ranked in descending order by the number of articles published (Table 7).

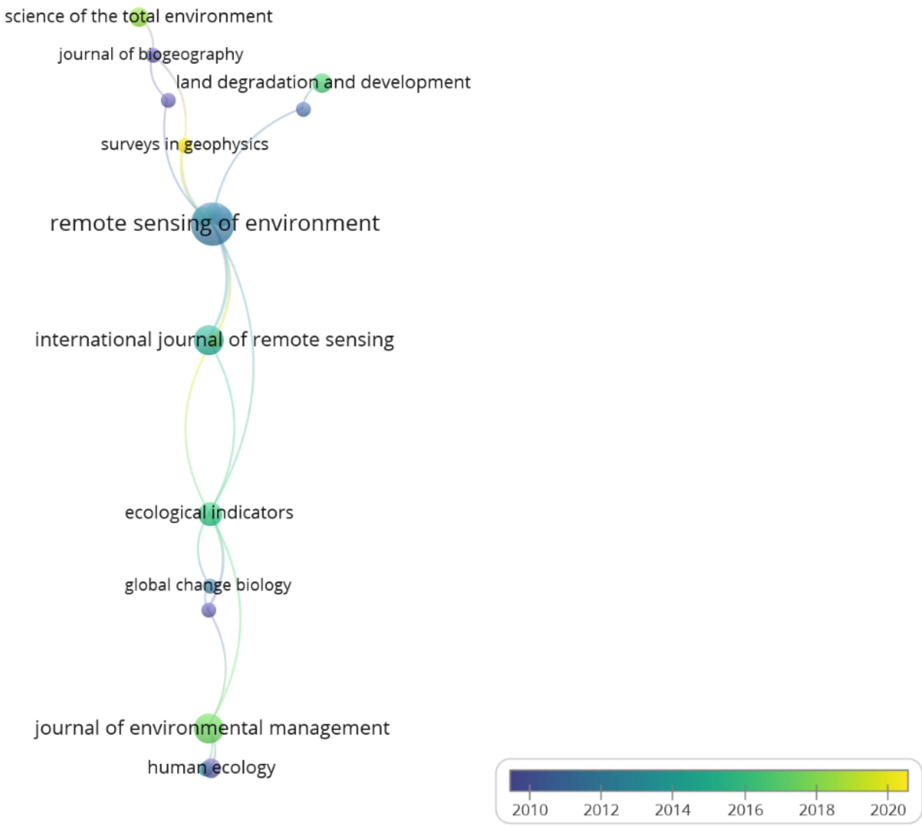
Table 7 – Journal's contribution.

Journal	Articles	Citations	Strength
Remote Sensing of Environment	13	1124	13
Journal of Environment Management	5	65	4
International Journal of Remote Sensing	5	206	3
ISPRS – Journal of Photogrammetry and Remote Sensing	4	40	0
Ecological Indicators	3	70	7
Fire Ecology	2	17	1
Forest Ecology and Management	2	13	1
Human Ecology	2	193	1
Land Degradation & Development	2	55	1
Science of the Total Environment	2	17	1
Ecological Applications	2	112	0
Ecology	2	325	0
Global Ecology and Biogeography	1	82	4
Surveys in Geophysics	1	2	4
Ecosystems	1	8	3
Journal of Biogeography	1	109	3
Agricultural and Forest Meteorology	1	51	2
Environmental Management	1	14	2
Global Change Biology	1	38	2
New Phytologist	1	34	1
PLOS One	1	34	1
Applied Geography	1	29	0
Austral Ecology	1	10	0
Community Ecology	1	98	0
Earth Interactions	1	25	0
Global Biogeochemical Cycles	1	32	0
Holocene	1	19	0
Perspectives in Plant Ecology, Evolution and Systematics	1	27	0
Photogrammetric Engineering & Remote Sensing	1	13	0
Remote Sensing Applications: Society and Environment	1	3	0
Sensors (Switzerland)	1	23	0
Nature Reviews Earth & Environment	1	24	0
Sustainability (Switzerland)	1	0	0
Revista Eletrônica Científica da UERGS	1	0	0
Revista Brasileira de Meio Ambiente	1	0	0

Source: The authors (2021).

The collaborative relationship between journals demonstrated that only 18 had connection (Figure 9). Furthermore, the remote sensing area periodicals have a higher publications frequency about fire use between 2010 and 2020. However, others focused on ecology have a higher concentration in more recent years afterward 2020.

Figure 9 – Network cluster analysis of the connections between the journals and their distribution over time.

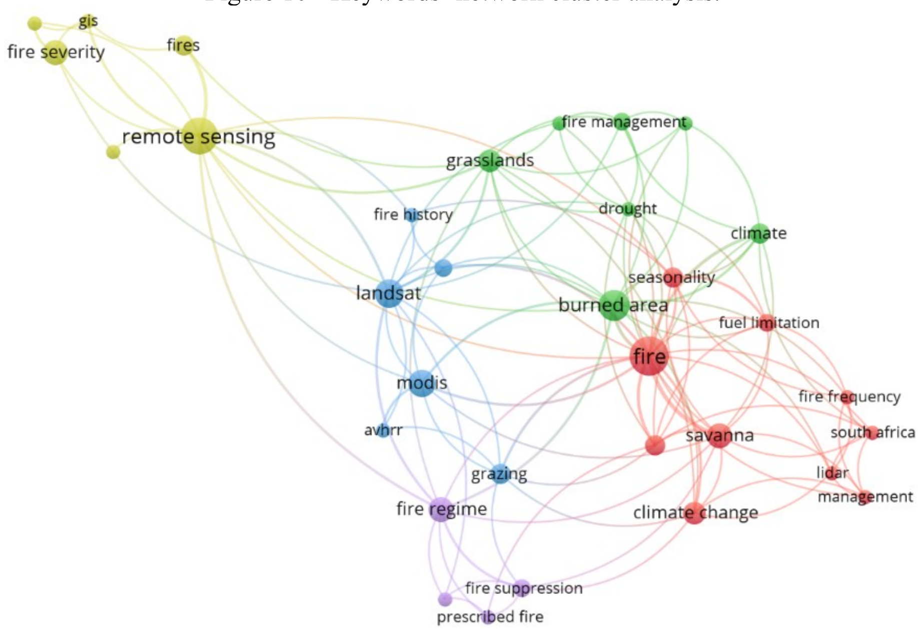


Source: The authors (2021).

3.6 Principal topics and trends

This step created a review of articles' keywords cluster maps to understand their frequency and co-occurrence (Figure 10) and temporal trend (Figure 11). Note that keywords appearing only once were not used so that the grouping would be more realistic and without noise.

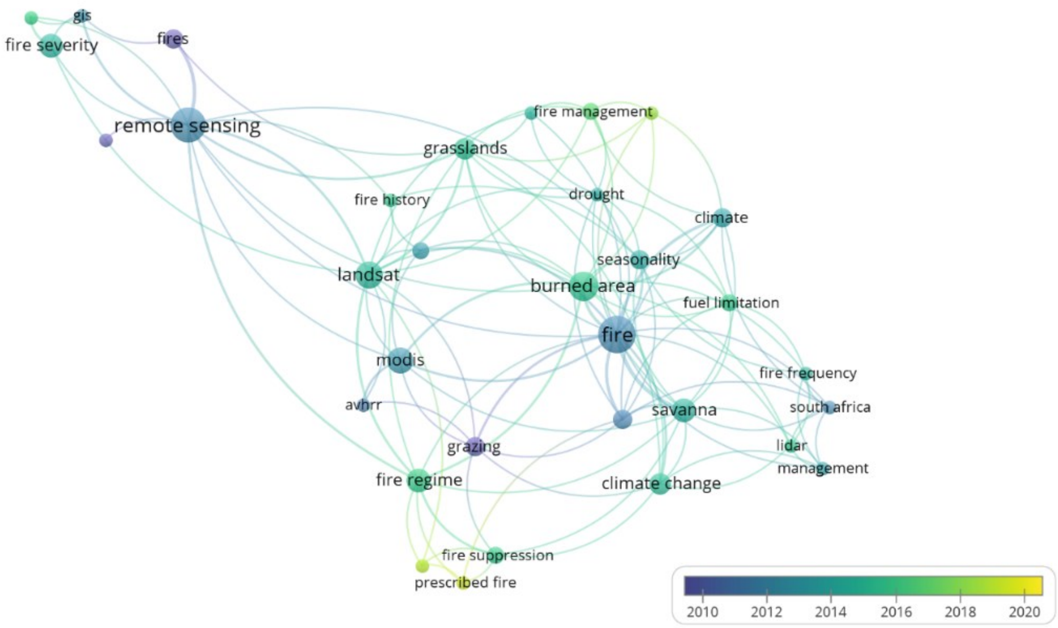
Figure 10 - Keywords' network cluster analysis.



Source: The authors (2021).

The keywords' distribution reveals a certain consolidation of some research topics, specifically those related to the use of time series such as from Landsat and MODIS, as well as the emergence of other topics related to the application of spectral indices for fire severity analysis and vegetation recovery.

Figure 11 - Network cluster analysis of keyword trends over time.



Source: The authors (2021).

When analyzing the keyword clusters and their distribution over time (Figure 11), it was seen that wildfire burns and pasture grazing appeared in higher concentration starting in 2010. This trend may be related to the growing use of time series to estimate burned areas for pasture. Another reason might be the need to evaluate how socioeconomic shifts contribute to changes in land use and cover, as well as assessing whether there are specific disturbance agents. In arid areas, the decline of grazing could result in the transition of the ecosystem to different state. However, vegetation changes due to reduced grazing probably led to a switch of practices with fire being the new primary disturbance agent (DUBININ *et al.*, 2010).

Therefore, fire propagation requires information about its occurrence, danger, and influence. Fire conditions vary significantly in time and space, for example, fuel requires time to accumulate, and the topography and microclimate influence the fuel conditions. Remote sensing measurements meet these requirements and are particularly useful for investigating the history of burns (ELMORE; ASNER; HUGHES, 2005).

Between 2012 and 2016, an increase in publications addressing climate change and drought can be seen. It is known that prolonged seasonal drought linked to the water regime is strongly connected to the fire regime (NELSON *et al.*, 2012). Therefore, climate change may influence these conditions, compromising the aboveground biomass, with adverse effects on the pasture's health, presenting significant challenges not only to biodiversity conservation, but also to farmers and the subsistence of communities in general (SHOKO; MUTANGA; DUBE, 2016).

Finally, it is worth highlighting that in more recent years, between 2018 and 2020, the subjects "prescribed burning," "post-fire recovery," and "integrated fire management" point to the current trend in remote sensing studies of fire use in grasslands. Usually, it is correlated with integrated management and conservation to reduce fire's intensity and severity. These trends can make fire events more controllable and reduce their negative impacts.

Fire continues to be used around the world by society for various reasons, including agriculture, stimulating plant flowering/fruiting and regrowth, fuel load reduction, species prevention and selection, and pest eradication, among other uses. Remote sensing of burn areas has changed our view of burn patterns and the understanding of the causes and impacts of fires on regional, continental, and global scales (CHUVIECO et al., 2019). Earth observation can meaningfully support prescribed grassland burns, abetting the identification of crucial factors in these decisions.

4 CONCLUSION

The systematic review using the PRISMA method done in this study initially identified 7,881 articles in the scientific literature, which the subsequent eligibility step reduced to 67. These were used in the meta-analysis, where their information was cataloged by means of tables and cluster analysis maps.

The primary objective of this systematic review was to assess the state of the art in fire behavior and use in grasslands via remote sensing. The results show the number of publications on the subject has been growing over the years and presents a growing trend, verifying the scientific community's interest. The United States and Brazil have the most authors working on this subject. Brazil contributed approximately 16% of the articles and 7% of the citation as well as studies done in various biomes, confirming the subject’s importance in the country.

Of total number of publications analyzed, most of them, over 71%, used Landsat series or MODIS sensors. Currently, with the launch of satellites such as Sentinel, there has been an improvement in spatial, spectral, and temporal resolutions of orbital images used to estimate natural pasture biomass and to discriminate between grass species. Moreover, only 8% of publications used non-orbital data, with more than half of them published in the last five years, revealing the growth in obtaining images from UAV-mounted sensors.

It was found that spectral indices are an essential tool in the fire use analysis because they furnish details about their influence on landscape change and vegetation dynamics. Many of these indices, such as NDVI, NDWI, and EVI, have been used for a long time, while NBR has come to be more used in recent years when it started to be applied by connecting the burn severity concepts present in ecology to remote sensing.

Cluster analyses using keywords indicate a recent trend in spectral indices to analyze fire severity and vegetation recovery, considering biodiversity conservation and anthropic use integration, since fire studies seek to reduce its intensity and severity to make it more controllable and reduce its negative impacts.

Climate change has been influencing aboveground biomass in grasslands and, consequently, having environmental and social impacts. At the same time, some issues such as prescribed burns, post-fire vegetation recovery, and integrated fire management are studied more often through remote sensing.

Finally, it is important to stress that this study has some limitations, including the method of choosing articles and the source of the database used. For example, the systematic review could have been developed using other quantitative or qualitative methods or even other scientific article databases, such as Web of Science or Google Scholar, which could present different results, particularly citations. However, by adding some articles not found in Scopus, we tried to ameliorate this problem and demonstrate the state of the art in the fire behavior and use in grasslands using remote sensing techniques.

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Authors’ Contribution

The first author (Pâmela Boelter Herrmann) was responsible for Conceptualization, Data Curation, Formal Analysis, Research, Methodology, Visualization, Writing - initial draft, and Writing - review and editing. The second author (Victor Fernandez Nascimento) was responsible for Methodology, Supervision, Validation, Writing, Review, and Editing. The third author (Marcos Wellausen Dias de Freitas) was responsible for Supervision and Writing, Proofreading, and Editing.

Conflict of interest

The authors declare no conflict of interest.

References

ABDOLLAHI, M. *et al.* An advanced forest fire danger forecasting system: Integration of remote sensing and historical sources of ignition data. **Remote Sensing**, vol. 10, n. 6, 2018. DOI:10.3390/rs10060923.

ADAGBASA, E. G.; ADELABU, S. A.; OKELLO, T. W. Development of post-fire vegetation response-ability model in grassland mountainous ecosystem using GIS and remote sensing. **ISPRS Journal of Photogrammetry and Remote Sensing**, vol. 164, n. September 2019, p. 173–183, 2020. DOI:10.1016/j.isprsjprs.2020.04.006.

ALVARADO, S.T. *et al.* Drivers of fire occurrence in a mountainous Brazilian cerrado savanna: Tracking long-term fire regimes using remote sensing. **Ecological Indicators**, vol. 78, p. 270–281, 2017. DOI:10.1016/j.ecolind.2017.02.037.

ALVARADO, S.T.; SILVA, T.S.F.; ARCHIBALD, S. Management impacts on fire occurrence: A comparison of fire regimes of African and South American tropical savannas in different protected areas. **Journal of Environmental Management**, vol. 218, p. 79–87, 2018. DOI:10.1016/j.jenvman.2018.04.004.

BOND, W J; WOODWARD, F I; MIDGLEY, G F. The global distribution of ecosystems in a world without fire. **New Phytologist**, vol. 165, n. 2, p. 525–538, 2005. DOI: 10.1111/j.1469-8137.2004.01252.x.

BOWMAN, D. M. J. S. *et al.* Vegetation fires in the Anthropocene. **Nature Reviews Earth & Environment**, vol. 1, n. 10, p. 500–515, 2020. DOI: 10.1038/s43017-020-0085-3.

BUCHHORN, M. *et al.* **Copernicus Global Land Service: Land Cover 100m: collection 3: epoch 2019: Globe. 2020**. DOI:10.5281/ZENODO.3939050.

CHEN, D. *et al.* Mapping fire regimes in China using MODIS active fire and burned area data. **Applied Geography**, vol. 85, p. 14–26, 2017. DOI: 10.1016/j.apgeog.2017.05.013.

CHUVIECO, E. *et al.* Historical background and current developments for mapping burned area from satellite Earth observation. **Remote Sensing of Environment**, vol. 225, n. February, p. 45–64, 2019. DOI: 10.1016/j.rse.2019.02.013.

CRUSIOL, L.G. *et al.* Reflectance calibration of UAV-based visible and near-infrared digital images acquired under variant altitude and illumination conditions. **Remote Sensing Applications: Society and Environment**, vol. 18, 2020. DOI: 10.1016/j.rsase.2020.100312.

DÍAZ-DELGADO, R.; LLORET, F.; PONS, X. Influence of fire severity on plant regeneration by means of remote sensing imagery. **International Journal of Remote Sensing**, vol. 24, n. 8, p. 1751–1763, 2003. DOI: 10.1080/01431160210144732.

DIPAOLO, D. A. Grassland and Shrublands - An Overview. **Native Ecosystems**, vol. 3, n. 2016, p. 414–423, 2020. DOI: 10.1016/B978-0-12-409548-9.12456-X.

DUBININ, M. *et al.* Reconstructing long time series of burned areas in arid grasslands of southern Russia by satellite remote sensing. **Remote Sensing of Environment**, vol. 114, n. 8, p. 1638–1648, 2010. DOI: 10.1016/j.rse.2010.02.010.

ECK, N. J. V.; WALTMAN, Ludo. VOSviewer Manual. **Manual for VOSviewer version 1.6.16**, n. November, 2020.

ELMORE, A.J.; ASNER, G.P.; HUGHES, R.F. Satellite monitoring of vegetation phenology and fire fuel conditions in Hawaiian drylands. **Earth Interactions**, vol. 9, n. 1, 2005.

ESKANDARI, R.; MAHDIANPARI, M.; MOHAMMADIMANESH, F. Meta-analysis of Unmanned Aerial Vehicle (UAV) Imagery for Agro-environmental Monitoring Using Machine Learning and Statistical Models. **Remote Sensing**, vol. 12, n. 3511, p. 1–30, 2020. DOI: 10.3390/rs12213511.

EVANGELIDES, C.; NOBAJAS, A. Red-Edge Normalised Difference Vegetation Index (NDVI705) from Sentinel-2 imagery to assess post-fire regeneration. **Remote Sensing Applications: Society and Environment**, vol. 17, n. July 2019, p. 100283, 2020. DOI: 10.1016/j.rsase.2019.100283.

FERNÁNDEZ-GUISURAGA, J. M.; CALVO, L.; SUÁREZ-SEOANE, S. Comparison of pixel unmixing models in the evaluation of post-fire forest resilience based on temporal series of satellite imagery at moderate and very high spatial resolution. **ISPRS Journal of Photogrammetry and Remote Sensing**, vol. 164, n. February, p. 217–228, 2020. DOI: 10.1016/j.isprsjprs.2020.05.004.

FRANKE, J. *et al.* Fuel load mapping in the Brazilian Cerrado in support of integrated fire management. **Remote Sensing of Environment**, vol. 217, n. January, p. 221–232, 2018. DOI: 10.1016/j.rse.2018.08.018.

GAO, B. NDWI A Normalized Difference Water Index for Remote Sensing of Vegetation Liquid Water From Space. **Remote Sensing of Environment**, vol. 58, n. 3, p. 257–266, 1996. DOI: 10.24059/olj.v23i3.1546.

GARNER, R. M. *et al.* Bibliometric indices : Defining academic productivity and citation rates of researchers, departments and journals. **Journal of NeuroInterventional Surgery**, vol. 10, n. 2, p. 102–106, 2018. DOI:10.1073/pnas.0507655102.

GIGLIO, L. *et al.* Assessing variability and long-term trends in burned area by merging multiple satellite fire products. **biogeociences**, n. 2008, p. 1171–1186, 2010. DOI: 10.5194/bg-7-1171-2010.

GOODWIN, N.R.; COLLETT, L.J. Development of an automated method for mapping fire history captured in Landsat TM and ETM+ time series across Queensland, Australia. **Remote Sensing of Environment**, vol. 148, p. 206–221, 2014. DOI: 10.1016/j.rse.2014.03.021.

GUERINI FILHO, M.; KUPLICH, T. M.; QUADROS, F. L. F. Estimating natural grassland biomass by vegetation indices using Sentinel 2 remote sensing data. **International Journal of Remote Sensing**, vol. 41, n. 8, p. 2861–2876, 2020. DOI: 10.1080/01431161.2019.1697004.

HAKALA, T. *et al.* Direct reflectance measurements from drones: Sensor absolute radiometric calibration and system tests for forest reflectance characterization. **Sensors (Switzerland)**, vol. 18, n. 5, 2018. DOI: 10.3390/s18051417.

HE, Y.; YANG, J.; GUO, X. Green Vegetation Cover Dynamics in a Heterogeneous Grassland: Spectral Unmixing of Landsat Time Series from 1999 to 2014. **Remote Sensing**, vol. 12, n. 22, p. 3826, 2020. DOI: 10.3390/rs12223826.

HOFFMANN, W. A. *et al.* Ecological thresholds at the savanna-forest boundary : how plant traits, resources and fire govern the distribution of tropical biomes. **Ecology Letters**, vol. 15, p. 759–768, 2012. DOI: 10.1111/j.1461-0248.2012.01789.x.

HUETE, A. R. A soil-adjusted vegetation index (SAVI). **Remote Sensing of Environment**, vol. 25, n. 3, p. 295–309, 1988. DOI: 10.1016/0034-4257(88)90106-X.

HUETE, A. R.; *et al.* A Comparison of Vegetation Indices over a Global Set of TM Images for EOS-MODIS. **Remote Sensing of Environment**, vol. 59, p. 440–451, 1997. DOI: 10.1016/S0020-1693(00)85959-9

KEELEY, J.E.; BRENNAN, T.; PFAFF, A.H. Fire severity and ecosystem responses following crown fires in California shrublands. **Ecological Applications**, vol. 18, n. 6, p. 1530–1546, 2008. DOI: 10.1890/07-0836.1.

KEY, C. H.; BENSON, N. C. Landscape Assessment (LA) sampling and analysis methods. **USDA Forest Service - General Technical Report RMRS-GTR**, no. 164 RMRS-GTR, 2006.

MOHER, D. *et al.* Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. **PLoS Medicine**, vol. 6, n. 7, 2009. DOI: 10.1371/journal.pmed.1000097.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA). MODIS: Moderate Resolution Imaging Spetroradiometer. Disponível em: <https://modis.gsfc.nasa.gov/about/>. Acesso em: 05 mar. 2021.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (NASA). FIRMS: Fire Information for Resource Management System. Disponível em: <https://firms.modaps.eosdis.nasa.gov/>. Acesso em: 15 jan. 2022.

NELSON, D.M. *et al.* Long-term variability and rainfall control of savanna fire regimes in equatorial East Africa. **Global Change Biology**, vol. 18, n. 10, p. 3160–3170, 2012. DOI: 10.1111/j.1365-2486.2012.02766.x.

OLIVEIRA, J. M.; PILLAR, V. D. Vegetation dynamics on mosaics of Campos and Araucaria forest between 1974 and 1999 in Southern Brazil. **Community Ecology**, vol. 5, n. 2, p. 197–202, 2004. DOI: 10.1556/ComEc.5.2004.2.8.

PEREIRA, A. C. J. *et al.* Modelling fire frequency in a Cerrado savanna protected area. **PLoS ONE**, vol. 9, n. 7, 2014. DOI: 10.1371/journal.pone.0102380.

RAMPANT, P.; ZDUNIC, K.; BURROWS, N. UAS and Landsat imagery to determine fuel condition for fire behavior prediction on spinifex hummock grasslands of arid Australia. **International Journal of Remote Sensing**, vol. 40, n. 24, p. 9126–9139, 2019. DOI: 10.1080/01431161.2019.1651950.

ROUSE, J.W; HASS, j. a.; SCHELL, j. A. Monitoring vegetation systems in the great plains with ERTS. **Oxford University**, vol. 1, n. NASA-Earth Resources Technology Satellite Symposium, p. 309–317, 1973.

ROY, D.P. *et al.* Prototyping a global algorithm for systematic fire-affected area mapping using MODIS time series data. **Remote Sensing of Environment**, vol. 97, n. 2, p. 137–162, 2005. DOI: 10.1016/j.rse.2005.04.007.

SANTOS, F.L.M. *et al.* Assessing VIIRS capabilities to improve burned area mapping over the Brazilian Cerrado. **International Journal of Remote Sensing**, vol. 41, no. 21, p. 8300–8327, 2020. Available at: https://doi.org/10.1080/01431161.2020.1771791.

SHEFFIELD, J. *et al.* Satellite Remote Sensing for Water Resources Management : Potential for Supporting Sustainable Development in Data-Poor Regions. **Water Resources Research**, vol. 54, p. 9724–9758, 2018. DOI: 10.1029/2017WR022437.

SHEYKHMOUSA, M. *et al.* Support Vector Machine Versus Random Forest for Remote Sensing Image Classification: A Meta-Analysis and Systematic Review. **Journal of Selected Topics in Applied Earth Observations and Remote Sensing**, vol. 13, p. 6308–6325, 2020. DOI: 10.1109/JSTARS.2020.3026724.

SHOKO, C.; MUTANGA, O.; DUBE, T. Progress in the remote sensing of C3 and C4 grass species aboveground biomass over time and space. **ISPRS Journal of Photogrammetry and Remote Sensing**, vol. 120, p. 13–24, 2016. DOI: 10.1016/j.isprsjprs.2016.08.001.

SLINGSBY, J. A. *et al.* ISPRS Journal of Photogrammetry and Remote Sensing Near-real time forecasting and change detection for an open ecosystem with complex natural dynamics. **ISPRS Journal of Photogrammetry and Remote Sensing**, vol. 166, n. December 2019, p. 15–25, 2020. DOI:10.1016/j.isprsjprs.2020.05.017.

STAVER, A.C.; ARCHIBALD, S.; LEVIN, S. Tree cover in sub-Saharan Africa: Rainfall and fire constrain forest and savanna as alternative stable states. **Ecology**, vol. 92, n. 5, p. 1063–1072, 2011. DOI:10.1890/10-1684.1.

SU, H.; LEE, P. C. Mapping knowledge structure by keyword co-occurrence: a first look at journal papers in Technology Foresight. **Scientometrics**, vol. 85, p. 65–79, 2010. DOI: 10.1007/s11192-010-0259-8.

SZPAKOWSKI, David; JENSEN, Jennifer. A Review of the Applications of Remote Sensing in Fire Ecology. **Remote Sensing**, Cham, vol. 11, n. 22, p. 2638, 2019. DOI: 10.3390/rs11222638.

TAMIMINIA, H. *et al.* Google Earth Engine for geo-big data applications : A meta-analysis and systematic review ISPRS Journal of Photogrammetry and Remote Sensing Google Earth Engine for geo-big data applications : A meta-analysis and systematic review. **ISPRS Journal of Photogrammetry and Remote Sensing**, vol. 164, n. May, p. 152–170, 2020. DOI: 10.1016/j.isprsjprs.2020.04.001.

VIANA, J. *et al.* Remote Sensing in Human Health : A 10-Year Bibliometric Analysis. **Remote Sensing**, vol. 9, no. 12, p. 1225, 2017. Available at: https://doi.org/10.3390/rs9121225.

WALTMAN, L.; VAN ECK, N. J. A smart local moving algorithm for large-scale modularity-based community detection. **European Physical Journal B**, vol. 86, n. 11, 2013. DOI: 10.1140/epjb/e2013-40829-0.

WANG, J. *et al.* Estimating leaf area index and aboveground biomass of grazing pastures using Sentinel-1, Sentinel-2 and Landsat images. **ISPRS Journal of Photogrammetry and Remote Sensing**, vol. 154, n. January, p. 189–201, 2019. DOI:10.1016/j.isprsjprs.2019.06.007.

WANG, R.; MURAYAMA, Y.; MORIMOTO, T. Scenario simulation studies of urban development using remote sensing and GIS : review. **Remote Sensing Applications: Society and Environment**, vol. 22, n. January, p. 100474, 2021. DOI: 10.1016/j.rsase.2021.100474.

WILLIAMSON, G.J.; MURPHY, B.P.; BOWMAN, D.M.J.S. Cattle grazing does not reduce fire severity in eucalypt forests and woodlands of the Australian Alps. **Austral Ecology**, vol. 39, n. 4, p. 462–468, 2014. DOI: 10.1111/aec.12104.

WULDER, M. A. *et al.* Biomass status and dynamics over Canada's forests: Disentangling disturbed area from associated aboveground biomass consequences. **Environmental Research Letters**, vol. 15, n. 9, 2020. DOI: 10.1088/1748-9326/ab8b11.

XU, D. *et al.* Measuring the dead component of mixed grassland with Landsat imagery. **Remote Sensing of Environment**, vol. 142, p. 33–43, 2014. DOI: 10.1016/j.rse.2013.11.017.

YANG, L. *et al.* An analysis of relationships among climate forcing and time-integrated NDVI of grasslands over the U.S. northern and central Great Plains. **Remote Sensing of Environment**, vol. 65, n. 1, p. 25–37, 1998. DOI: 10.1016/S0034-4257(98)00012-1.

YEBRA, M. *et al.* A global review of remote sensing of live fuel moisture content for fire danger assessment: Moving towards operational products. **Remote Sensing of Environment**, vol. 136, p. 455–468, 2013. DOI: 10.1016/j.rse.2013.05.029.

Biography

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