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ORIGINAL PAPER

A bibliometric analysis for remote sensing applications in bush encroachment mapping of grassland and savanna ecosystems

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Abstract

Grasslands and savannas are experiencing transformation and degradation due to bush encroachment (BE). BE has been monitored using restrictive traditional techniques that include field surveys and manual long-term observations. Owing to the limitations of traditional techniques, remote sensing (RS) is an attractive alternative to assess BE because of its generally high precision and return interval, cost-effectiveness, and availability of historical data archives. Furthermore, RS has an added advantage in its ability of acquiring global coherent data in near-real time compared to the snapshot acquisition mode with traditional surveying techniques. Despite its extensive application and vast possibilities, a critical synthesis for RS successes, shortcomings, and best practices in mapping BE in savannas and grasslands is lacking. Thus, broadly, the direction, which this type of investigation has taken over the years is largely unknown. This study sought to connect and measure the progress RS has made in mapping BE in grassland and savanna ecosystems through bibliometric analysis. One hundred and twenty-three peer-reviewed English written documents from the Web of Science and Scopus databases were evaluated. The study revealed 13.05% average annual publication growth, indicating that RS and BE mapping research in grasslands and savannas has been increasing over the survey period. Most published studies came from the USA, while the rest came from South Africa, China, and Australia. The results indicate that BE has been extensively mapped in grasslands and savannas using coarse to medium resolution data. As a result, there is a weak relationship ($r^2 = 0.324$) between the dependent variable (aerial images) and the independent variable (percentage of woody cover). This connotes the need to improve BE assessments in grasslands and savannas by integrating recent high-resolution data, machine learning algorithms and artificial intelligence.

Keywords Remote sensing · Bush encroachment · Mapping · Bibliometric · Grassland · Savanna ecosystems

Introduction

Globally, grasslands, particularly those in savannas are amongst the dominant ecosystems covering approximately 37% of land (O’Mara 2012). Grasslands consist of a variety of grass species, herbs, legumes, and clover (Carlier et al. 2009; Masenyama et al. 2022). Savannas consist of a ground cover of grasses and a canopy of trees (Beckage et al. 2011). Grasslands and savannas contribute to biodiversity conservation and supply numerous ecosystem services (Bengtsson et al. 2019; Habel et al. 2013; Masenyama et al. 2022). For example, they are habitats for numerous vegetation species (Muller et al. 2021; Osborne et al. 2018), birds, animals, and insects (John and Jaoa 1991; Osborne et al. 2018). Grassland and savannas act as carbon sinks and reduce available atmospheric carbon dioxide, which is one of the causes of global warming (Abberton et al. 2010). They serve the needs of human beings, such as shelter, food, and economic needs, which are met through mining, agriculture, and industries (Matsika 2007). Similarly, grasslands and savannas play a crucial role as the primary source of forage for livestock and wild animals (Carlier et al. 2009; Wachiye et al. 2022).

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Despite providing various ecosystem services, they have been highly transformed and consequently are critically endangered (Botha et al. 2017) facing continued degradation (Khazieva et al. 2022; Mokgosi 2018).

Bush encroachment (BE) refers to the intensification of woody plant species (Kellner et al. 2022) and is experienced in many parts of the world (Knapp et al. 2008; O'Connor et al. 2014) such as North America (Archer et al. 2017), Africa (O'Connor et al. 2014), Asia (Khazieva et al. 2022) and Australia (Acharya et al. 2018). Many studies of BE have documented the changes it causes in the encroached ecosystems. Soubry and Guo (2022) noted that BE led to alteration of biodiversity, which resulted in decreased habitat for animals and plants. Tokozwayo et al. (2018) observed BE to be a danger to livestock production as it reduced grazing land. Liao et al. (2018) described that BE can change the functioning of the ecosystem. In addition, Acharya et al. (2018) observed that BE affects groundwater recharge. Considering the continuous occurrence of BE and its negative impacts, monitoring of grasslands and savannas becomes an important issue that requires special attention. This latter will assist working towards achieving targets 5 and 8 of the Sustainable Development Goal (SDG) 15, which focus on protecting biodiversity, natural habitats, and preventing alien species.

Management and monitoring of BE requires a crucial understanding of its driving factors. These include high grazing pressure, fire, rainfall (Archer et al. 2017), increased carbon dioxide (CO_2) (Ward 2005), and croplands abandonment (Mndela 2020). Grazing patterns such as intensive and prolonged sketchy grazing give way to BE proliferation (Zhang et al. 2019). Fire limits the survival and growth of bush plant species (O'Connor et al. 2014) whereas its rare occurrence propagates BE as there is no limiting factor in bush growths (Gordijn 2010). In addition, climatic variables such as rainfall influence the spread of BE since woody plants thrive under high quantities of water (Kgosikoma and Mogotsi 2013). Similarly, increased CO_2 concentrations contribute to the spread of BE as increased CO_2 directly elevates plant photosynthetic activity (O'Connor et al. 2022). BE also occurs in abandoned croplands as a result of a bequest of soil nutrients such as phosphorus and nitrogen (Moyo and Ravhuhali 2022). It is evident that there are many causes of BE which are similar in many instances but others differ from place to place. Therefore, it is crucial to determine the other important factors that exacerbate BE through a literature search to assist in its monitoring and management.

In monitoring the spread of bush encroachment, traditional methods such as manual long-term field experiments have been used (Cipriotti and Aguiar 2012; Schröter et al. 2011). The manual field experiments include evaluation of bush densities (Schröter et al. 2011), calculating the number of bushes in each quadrant and taking pictures during field visits. However, these methods are restrictive because of high costs, labour intensity, limited area coverage, lengthy revisit time, and poorly document the differences in encroachment patterns (Ludwig et al. 2016; Cao et al. 2019). Due to these limitations, remote sensing (RS) has been integrated into BE research due to its cost-effectiveness, high spatial and temporal resolutions, and its ability to document spatial heterogeneity of encroaching woody plant species (Cao et al. 2019; Urban et al. 2021). Similarly, RS has the ability to generate world-wide data in real-time (Liang and Jindi 2020) providing a synoptic view of the present. The usefulness of RS in studying BE is because of its historic archive data that allows for long-term investigations. Also, RS can assist in studying the impacts, spread, and understanding of the driving factors of bush encroachment (Oddi et al. 2021). RS is essential in the study of BE and has been applied since the inception of the idea of obtaining photographs above the earth's surface. Over time, remote sensing tools have evolved from aerial photographs to satellite images with coarse resolutions, to satellite images with finer resolutions, to the invention and use of Unmanned Aerial Vehicles (UAV).

Previous studies of RS applications to BE include Asner et al. (2003) who utilized aerial photographs, Landsat-5 Thematic Mapper (TM) imagery, Landsat 7 Enhanced Thematic Mapper (ETM) + imagery and field observations to evaluate changes in woody plant cover and carbon stocks in an area of 400 km^2. Ludwig et al. (2019) utilized machine learning, Sentinel-1, and Sentinel-2 sensors to model the status and predict woody plant vegetation in Molopo area in South Africa. Oldeland et al. (2010) mapped BE based on seasonal differences using hyperspectral images of HYMAP imaging spectrometer. Shekede et al. (2015) assessed BE using an intensity-dominant scale approach on 2-meter historical aerial photographs and GEOEYE satellite images. Lastly, Graw et al. (2016a) mapped BE in Africa using Landsat-5 TM, Landsat-8 Operational Land Imager (OLI), and Moderate Resolution Imaging Spectroradiometer (MODIS). The above studies are amongst the many successful studies that show the success of the applications of remote sensing in mapping bush encroachment and where more work needs to be done.

There have been many reviews, which have been conducted on bush encroachment on grasslands and savannas (Aweto 2024; Shikangalah and Mapani 2020; O'Connor et al. 2014; D'Odorico et al. 2012; Abule 2008). However, their focus was not on RS applications in mapping BE in grasslands and savannas. Reviews that focussed on the application of RS on bush encroachment in grasslands and savanna include (Maphanga et al. 2022; Masenyama et al. 2022;

Soubry and Guo 2021; Cao et al. 2019). For example, Soubry and Guo (2022) focused on remote sensing techniques for determining bush encroachment in grasslands. Similarly, Maphanga et al. (2022) reviewed the progress of utilizing remote sensing in monitoring BE that is influenced by climate change. Also, Cao et al. (2019) reviewed studies on BE processes and mechanisms, monitoring and its modelling using remote sensing. Likewise, Masenyama et al. (2022) conducted a systematic review on utilizing remote sensing in measuring grasslands ecosystem services. However, the available literature is unclear on what the best practises are and what has not been successfully done. Hence, this study sought to conduct a systematic literature review to evaluate and measure the progress of RS in BE mapping on grassland and savanna ecosystems using bibliometric analysis. To the best of our knowledge, such a study has not been conducted.

Bibliometric analysis refers to the statistical analysis of issued books, and articles in a specific field of science (Iftikhar et al. 2019). Bibliometric analysis assists in comprehending research, progress (Halepoto et al. 2022a), and determining the impact that the publications have in the field of science (Iftikhar et al. 2019). This method can be utilized to show developing trends of published articles, the performance of journals, collaboration arrays, and others (Halepoto et al. 2022b). Bibliometric analysis assists in interpreting and charting the increase of scientific literature and the progression of specific fields by rationalizing huge quantities of unorganized information (Halepoto et al. 2022b). Therefore, this study attempted to utilize bibliometric analysis to address some pertinent objectives: (i) to investigate the research developments in bush encroachment mapping on grasslands and savanna ecosystems using remote sensing tools; (ii) to examine the current research themes on remote sensing applications to monitor bush encroachment in grasslands and savannas; (iii) to document the countries and publications that are significant in the use of RS to map bush encroachment in grasslands and savannas; (iv) and to analyze the most explored remote sensing tools and dataset applications on bush encroachment. The results of the study are expected to be helpful to researchers in the field of RS and Ecology in understanding what has been accomplished and future work that is still needed in mapping bush encroachment in grasslands and savannas using remote sensing tools.

Remote sensing platforms used to map bush encroachment

Various remote sensing tools have been used to map bush encroachment. Aerial photography was the first form of modern remote sensing (Ashraf et al. 2011) dating to the 1800s (Kupfer and Emerson 2005). Historical aerial photographs were obtained through balloons, kites and homing pigeons (Kupfer and Emerson 2005). Aircrafts were used later on in the early 1900s (Hoffer 1984). The obtained aerial photographs were characterised as grey tones, colour, and coloured infrared films (Hoffer 1984). The black and white film recorded information in the visible (0.4 to 0.7 μm) region of the electromagnetic spectrum (Civco 2015). At the same time, the coloured film and coloured infrared were sensitive in the visible regions and from 0.7 to 0.9 μm wavelength regions (Hoffer 1984). Coloured and coloured infrared aerial photographs are more valuable than black and white photographs in BE studies as different vegetation species such as herbs, woody plants, and forbs, can be determined (Hoffer 1984). The significance of historical aerial photographs in BE mapping is that they have a long archive of data, high spatial resolution, easy-to-obtain data almost anywhere, limited atmospheric noise and provision of a valuable window into the past (Morgan et al. 2010). Examples of studies that utilised aerial photography in mapping bush encroachment were conducted by (Hudak and Wessman 1997; Whiteman and Brown 1998; Laliberte et al. 2004). Whiteman and Brown (1998) evaluated a technique for mapping woody vegetation thickness using colour aerial photographs. The study was able to accurately detect shrubs with canopies bigger than 9 m^2. Laliberte et al. (2004) mapped bush encroachment from 1937 to 2003 using 86 cm spatial resolution aerial photographs. The study was able to detect shrubs that were smaller than 2 meters (m). Hudak and Wessman (1997) used textural analysis on aerial photographs and land use maps to determine bush bulks. The study obtained a correlation of $r^2 = 0.324$ when correlating image texture and woody canopy variables.

Modern or digital aerial photographs on the other hand, are obtained using helicopters (Laghari et al. 2023), Unmanned Aerial Vehicles (UAV) (Ahmad et al. 2013; Hristov et al. 2016), and aircrafts (Hoffer 1984). Like historical aerial photographs, digital aerial photographs have high spatial resolution, are easy to obtain at any place. Scale, spatial, spectral, and temporal characteristics are easily adjustable. Photographs are immediately available and can be digitally stored and copied without loss of data, and images undergo radiometric calibration procedures (Morgan et al. 2010). There are various types of UAVs that have been previously used to map bush encroachment. These UAVs include DJI™ Phantom 4 Pro (Oddi et al. 2021), DJI™ Phantom 4 standard, DJI™ Matrice 200 v2 drone (Costa et al. 2023), a Beihang University customized UAV called EY130 (Zhao et al. 2021) and Unmanned Aerial System (UAS) Light Detection and Ranging (LiDAR) MK8-3500 Mikrokopter (Madsen et al. 2020). UAVs are designed to carry specific sensors depending on their size and project application. Different sensors that can be mounted on UAVs include RGB (visible light), multispectral, hyperspectral, thermal sensors (Mohsan et al. 2023) and LiDAR (Madsen et al. 2020). Even though historical and digital aerial photographs have considerable advantages in mapping BE, however, their challenge is that they are not suitable for mapping at country scale due to limited battery flight time. This then makes usage of aerial photography at country scale expensive compared to satellite. However, these big scale limitations can be overcome by either fusion of aerial photographs with satellite images that cover larger area and by simulating satellite data from drone data.

Several satellite images have been used to map bush encroachment. These images were captured by space borne multispectral, space borne and ground-based hyperspectral sensors. These satellite images have different spatial resolutions ranging from less than 1 m to kilometres with different temporal resolutions. They also have different spectral resolutions with spectral bands in the visible region of the electromagnetic spectrum and other images with broader spectral resolutions consisting of the visible region, near infrared and shortwave infrared region. The commonly used satellite images for mapping BE in grasslands and savannas are listed in Table 1. Researchers have demonstrated the capabilities of various satellite images in mapping BE in grasslands and savannas. For example, Symeonakis et al. (2016) used Landsat-5 TM, Landsat-7 ETM, and Landsat-8 OLI to map woody plant cover in the North West province of South Africa. Their study accurately mapped woody cover with accuracies between 74% and 84%. Laliberte et al. (2004) used historical aerial photographs and QuickBird-2 to map bush encroachment from 1937 to 2003 in southern New Mexico. They concluded that shrubs were correctly classified on the QuickBird image compared to aerial photographs. This distinction is based on the different pixel sizes. Also, Nkhwanana et al. (2022) used Sentinel-2 multispectral imager (MSI) to map encroaching species *Seriphium plumosum* in South African rangelands. Their study concluded that Sentinel-2 MSI successfully mapped *Seriphium plumosum* with 95.48% and 97.42% accuracy.

Remote sensing classification methods for mapping bush encroachment

The application of remote sensing in mapping vegetation is based on variations of spectral characteristics of plants. Due to their unique spectral characteristics, vegetation can be differentiated and, therefore can be mapped (Xie et al. 2008). Since BE in grasslands disturbs the homogeneity of

Table 1 The table summarises remote sensing platforms used over time to map bush encroachment

Instrument name	Spatial resolution (m)	Study	References
Aerial photographs	0.3 m	The study mapped shrub cover using an object-based approach and investigated its link to topo-edaphic factors.	(Soubry et al. 2022)
Aerial photographs Quickbird-2	0.86 m 0.65 m	The study used image segmentation and object-oriented image classification to map shrub encroachment from 1937 to 2003 in southern New Mexico.	(Laliberte et al. 2004)
Sentinel-1 Sentinel-2 A	5 m and 20 m 10 m, 20 m, 60 m	The study estimated woody plant canopy biomass on abandoned agricultural land using multiple regressions on Sentinel-1 and Sentinel-2 data.	(Bucha et al. 2021)
Sentinel-2 MSI	10 m, 20 m, 60 m	The study evaluated Sentinel-2 MSI in mapping *Seriphium plumosum*. They used random forest and support vector machine classification.	(Nkhwanana et al. 2022)
Aerial photographs, Landsat-5 TM, Landsat-7 ETM +, Landsat-8 OLI images	0.5 m 30 m and 120 m 30 m, 15 m 30 m, 15 m	The study used random forest classification to evaluate the extent of bush encroachment.	(Symeonakis et al. 2016)
Aerial photographs and SPOT 4 (Satellite pour l'Observation de la Terre)	0.5 m 20 m	The study used sub-pixel classification to quantify bush encroachment using historical images.	(Sinthumule and Munyati 2014)
UAV RGB and multispectral UAV LiDAR	0.04 m 0.16 m 0.035 m	The study used multiple linear regression, random forest regression and support vector regressions with data obtained using a customized UAV called EY130 drone to predict above ground biomass comparing to LiDAR in an encroached grassland.	(Zhao et al. 2021)
DJI™ Phantom 4 Pro	30 m	The study used Visual photo interpretation and Semi-automatic classification on UAV images to identify and map bush encroachment in Subalpine grasslands.	(Oddi et al. 2021)
DJI™ Phantom 4 standard drone	0.0280 m	The study used object-based supervised classification to evaluate the accuracy of bush encroachment classification using UAV imagery.	(Costa et al. 2023)
UAS LiDAR MK8-3500 Mikrokopter	0.03 m	The study detected bush encroachment in a semi-grassland using built-in classification algorithm using OPALS software.	(Madsen et al. 2020)
MODIS Landsat-5	500 m 30 m	The study used random forest classification to map bush encroachment in Africa using MODIS and Landsat images.	(Graw et al. 2016b)

grasslands, it results in variation in vegetation spectral characteristics. To map or evaluate the extent of the spread of the encroaching woody plant species, it is essential to differentiate the encroaching species and the vegetation that coexists with it. Various classification methods have been used to identify or map encroaching woody plant species. These methods include pixel-based, sub-pixel-based and object-oriented methods (Li et al. 2014). Per-pixel classification techniques are based on the notion that each image pixel has a single feature class (Xu et al. 2005). These techniques can be categorised as supervised and unsupervised classification (Li et al. 2014).

The supervised classification technique requires predetermination of feature classes. Whereas the unsupervised classification technique does not require feature classes to be predetermined. Examples of supervised classification techniques are maximum likelihood, machine learning algorithms, distance to means, Mahalanobis distance whereas unsupervised classification includes k-means and ISODATA (Abburu and Babu Golla 2015). Both supervised and unsupervised classification methods are automated classification techniques that use algorithms to classify pixels into functional classes (Abburu and Babu Golla 2015). Several studies have utilised these classification techniques in mapping bush encroachment. For example, Symeonakis et al. (2016) used random forest, a supervised classification method, on Landsat-5 TM, Landsat-7 ETM +, and Landsat-8 OLI images to map bush encroachment in savannas of the North West province of South Africa. Their study obtained classification accuracies ranging from 74 to 84% balanced accuracies.

Pixel-based classification method is image segmentation, which refers to grouping similar pixels into fragments (Abburu and Babu Golla 2015). Studies often integrate image segmentation with object-based classification, focusing on classifying objects through image segmentation instead of per-pixel analysis (Myint et al. 2011). An example of such a study was conducted by Soubry et al. (2022), who used object-based techniques and support vector machine (SVM) classification to detect and map the spread of bush encroachment in grasslands. Their study obtained above 92% accuracy in mapping bush encroachment. Another study was conducted by Laliberte et al. (2004) who compared object-oriented classification and image segmentation in evaluating the extent of bush encroachment for 66 years in southern New Mexico. The findings of the study showed that there was an underestimation of grass and woody plants due to larger pixel size than the woody plants and grass. They suggested object-based classification was better than pixel-oriented classification when extracting information about woody plants in aerial photographs and high-resolution images. Another study by Symeonakis et al. (2016) used random forest and SVM to map *Seriphium plumosum* encroachers using Sentinel-2 MSI. The study obtained 97.42% and 95.48% classification accuracy and noted the dominance of grass and a small percentage of the encroaching species. Even though the pixel-based classifiers produced high accuracies in classification, they do not consider that a certain amount of reflectance resulting from the pixel of interest comes from neighbouring pixels (Townshend et al. 2000) and therefore results in unsatisfactory analysis (Blaschke 2010) with high level of misclassifications (Li et al. 2014).

Sub-pixel-based classification technique assumes that there is a mixture of vegetation in each pixel and, therefore variation in spectral signatures (Palaniswami et al. 2006). Various sub-pixel classification methods include neural networks, regression models, fuzzy classification, regression tree analysis, and spectral mixture analysis (Li et al. 2014). This method can precisely predict the land cover of an area (Li et al. 2014). Sinthumule and Munyati (2014) used a subpixel analysis method to map woody plant encroachment using historical imagery. The study obtained an overall classification accuracy of 83.3%, and they concluded that BE can be accurately mapped using sub-pixel classification. Mintesnot (2009) used supervised classification and spectral mixture to map BE in Borana rangelands. The study obtained better results using supervised classification than the spectral mixture analysis. Graw et al. (2016a) used regression models based on random forest supervised classification and machine learning algorithms to map bush encroachment in South Africa and Ethiopia. For South Africa, the study used aerial photographs as input to predict BE using Landsat-5 TM images in a random forest regression model. For Ethiopia, the study used classifications maps derived using ASTER images to predict BE using Landsat-5 TM images. Both studies (South Africa and Ethiopia) were up-scaled to predict BE using MODIS data where the study obtained predictions of $r^2 = 0.87$ in South Africa and $r^2 = 0.65$ for Ethiopia. The study described the prediction results of South Africa as the best results in comparison to Ethiopia prediction result because the r^2 value is closer to 1. r^2 is a statistical metric employed in regression analysis to assess how effectively the independent variables account for the variation in the dependent variable. In these studies, it measures the strength of the relationship between the independent variables (aerial photographs and ASTER images) and the dependent variables (Landsat-5 TM and MODIS images).

Materials and methods

Scientific literature search and data processing

This study used Scopus and Web of Science (WOS) Core Collection bibliographic databases to extract literature data for bibliometric analyses. The selected databases contain an extensive scientific literature of peer-reviewed articles, conference proceedings, books and other document types indexed in numerous journals (Mongeon and Paul-Hus 2016; Martín-Martín et al. 2021). The following search terms “bush encroachment” OR “woody plant encroachment” OR “shrub encroachment” OR “woody plant proliferation” OR “shrub thickening” OR “woody cover” AND “remotely sensed” OR “remote sensing” OR “satellite” OR “UAV” OR “drone” OR “mapping” OR “GIS” OR “map” OR “detection” OR “monitoring” AND “grassland” AND “savanna” were used to extract publications related to monitoring bush encroachment in savanna grasslands using remote sensing. The search criteria included title, abstract and keywords dated from 1998 to 2022. The year 1998 is the first year in which the keyword bush encroachment was found with remote sensing. The Boolean operators “AND” and “OR” combined the search terms and limited the research to specified terms. The search terms results produced 424 and 341 filtered English written documents on WOS and Scopus, respectively. All retrieved documents were merged into a single notepad bib text file for a tedious screening process resulting in 184 documents from the two databases. The other 581 documents were not considered as they were not relevant. From the 184 documents, R-software removed about 61 duplicates in all the screened documents (Gagolewski 2011). The bibliometric analysis was conducted on 123 documents using a freely available bibliometric R-package on RStudio v4.2.3 that provide a biblioshiny to generate metrics and diagrams presented in the study (Aria and Cuccurullo 2017). Biblioshiny is a web based platform that executes scientific mapping analysis utilising bibliometrix package (Aria and Cuccurullo 2017).

Table 2 The summary information retrieved from WOS and Scopus on remote sensing (RS) applications in mapping bush encroachment (BE) in grasslands and savannas

Description	Results
Timespan	1998:2022
Sources (Journals, Books, etc.)	60
Documents	123
Annual Growth Rate %	13.05
Document Average Age	6.64
Average citations per doc	27.2
References	886
Keywords Plus (ID)	847
Author’s Keywords	477
Authors	447
Single-authored docs	2
Co-Authors per Documents	4.78
International co-authorships %	7.317
Document Types	
Article	108
Conference paper	8
Proceedings paper	2
Review	5

Results

Attributes of Scopus and WOS databases

Table 2 presents characteristics of 123 document types (i.e., articles, conference papers, reviews, and proceedings papers) obtained from Scopus and WOS databases focussing on bush encroachment, remote sensing, grasslands, and savannas. The search terms used retrieved documents that were published between the years 1998 to 2022 period. The start year was 1998 because it is the year in which the keyword bush encroachment or its synonyms was found with remote sensing, grassland and savannas in documents. These documents were obtained from 60 sources, including journals, books etc., with 447 authors and 2 authors of single-authored published documents. The average growth rate of published documents was 13.05%, with average age rate of 6.64, 27.2 average citations per document and 886 references. Co-authorship per document was 4.78, with international co-authorship of 7.317%.

Annual trends of scientific publications on BE mapping using RS

The trend for global annual publications from 1998 to 2022 is shown in Fig. 1. The number of publications has been fluctuating over the years. Publications can be traced back to 1998 with 1 article published. The years 1999 and 2000, 2002 and 2005, experienced a decline in publications with 0 publications. The number of publications started to increase from 2001 to 2004 and in 2006 with 1 to 2 publications. Publications started to steadily increase from 2006, 2007, and 2008, ranging from 2 to 3 publications per year. However, since 2013, the publications started doubling in numbers, with more than 5 publications a year. The highest peak of publications was observed in 2022, where 19 articles were published. The increase in publications shows the growing importance of

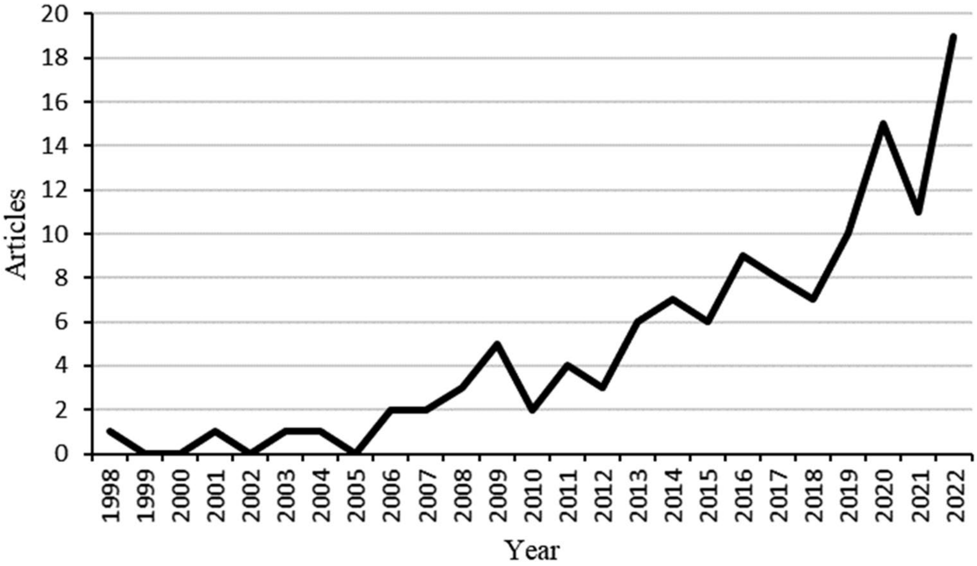

Fig. 1 Annual scientific publications on BE mapping using RS in grasslands and savannas from 1998 to 2022

Table 3 Top 10 most productive and cited countries per document on BE mapping using RS in grasslands and savannas from 1998 to 2022

Country	AP	TC	AAC
USA	80	1671	20.9
South Africa	31	473	15.3
Australia	20	143	7.15
China	15	197	13.13
Germany	12	165	13.75
Canada	6	25	4.2
United Kingdom	5	124	24.8
Italy	3	38	12.7
France	3	15	5
Cameroon	3	4	1.3

Note Article publications = AP, Total citations = TC, Average article citations = AAC

remote sensing in mapping bush encroachment in grasslands and savannas.

Spatial distribution and most cited scientific research per country

The study shows the top 10 globally cited countries in monitoring and mapping BE using RS for grasslands and savanna ecosystems, as shown in Table 3. The most productive countries were evaluated using published articles and total citations. However, average article citations were an additional criterion for the selected countries. The results showed that USA in North America was the most productive country with 80 article publications (AP) with the highest total citation (TC) (1671) and an average article citation (AAC) of 20.9. Whereas South Africa was the second highest publishing country with 31 AP, 473 TC and 15.3 AAC. A few publications from five and below were observed in United Kingdom (UK), and Italy, etc. Even though Italy, France and Cameroon had the equal AP (3). The high citation of these countries indicates their influence on the BE and RS research.

Figure 2 shows the spatial distribution of published articles on BE mapping using RS in grasslands and savannas from 1998 to 2022. The map shows that there were no published articles in Russia and only Chile in South America published one document. In the African continent, only South Africa, Namibia, Zimbabwe, Ethiopia, and Cameroon have published research on BE mapping using RS in grasslands and savannas.

Journal analysis

In the survey period, a total of 60 journals published research on bush encroachment mapping with the application of RS in grasslands and savannas. Figure 3 shows the top 10 journals that published articles on bush encroachment mapping with the application of remote sensing in grasslands and savannas. The Remote Sensing of Environment journal with $n = 16$ published articles, ranked top in article publications, followed by the Remote Sensing journal with $n = 14$ article publications and the International Journal of Applied Earth Observation and Geoinformation with $n = 8$ article publications. The high ranking of these journals indicates that they are the most information-disseminating journals of BE and RS-related research.

Explored topics, authors keywords, and co-occurrence

Figure 4 shows the word cloud of regularly appearing keywords in bush encroachment mapping using remote sensing in grasslands and savannas research. In the word cloud, the

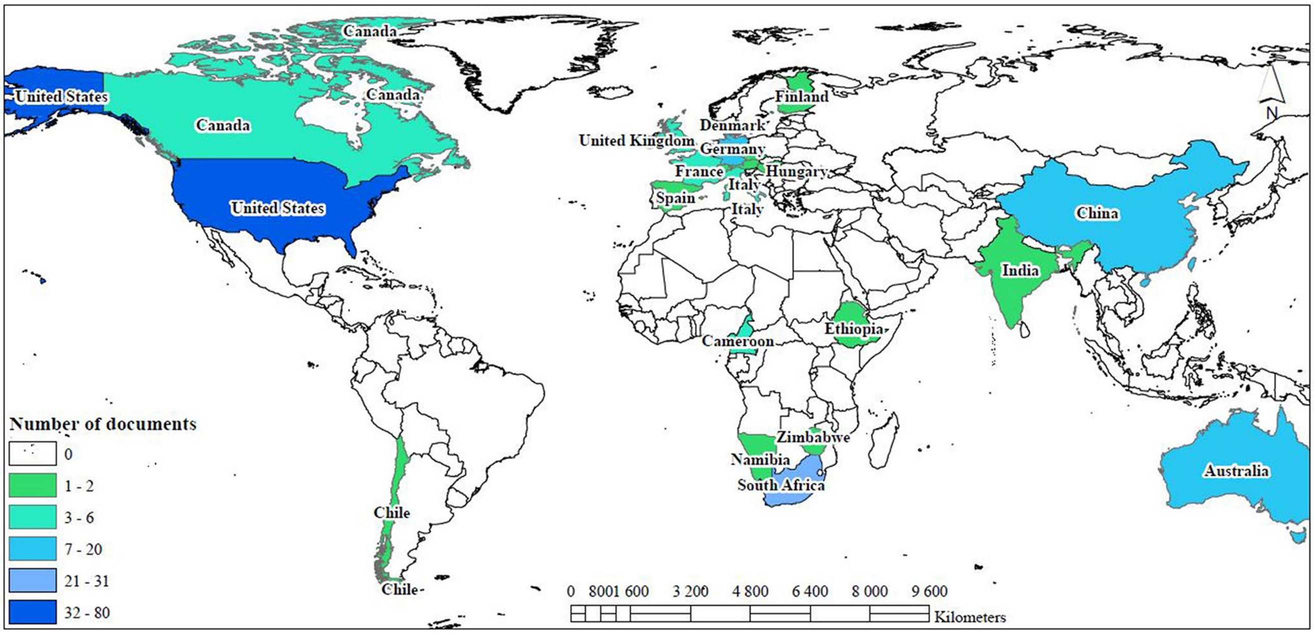

Fig. 2 Spatial distribution of scientific research produced where RS was used to map BE in grasslands and savannas over the survey period 1998 to 2022

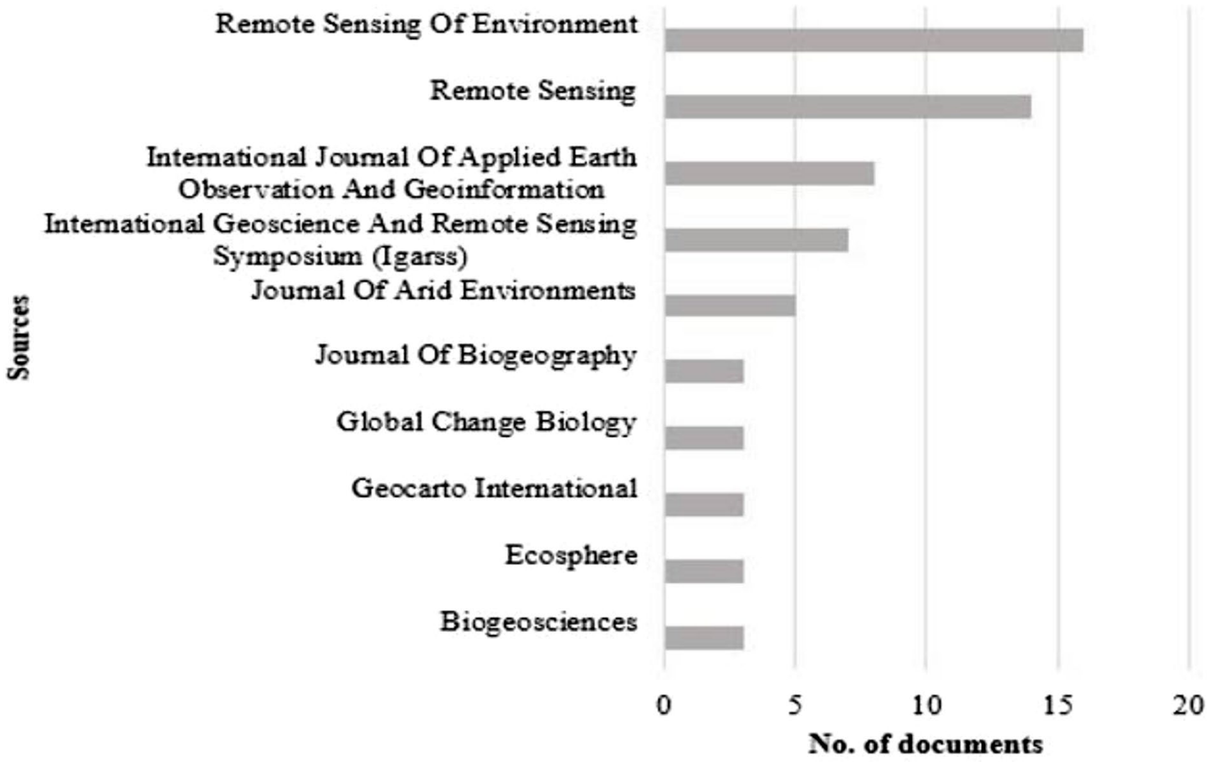

Fig. 3 Top 10 journals of article publications on bush encroachment mapping with application of remote sensing from 1998 to 2022

bigger the magnitude of each keyword indicates its dominance and frequent use of the word. Figure 4 shows that in bush encroachment mapping research, bush encroachment in grassland and savannas was mapped using remote sensing. Hence, the big size of words in the word cloud makes it easy to determine the current focus areas in the BE mapping using RS in grasslands and savannas. The words written in smaller font indicate the research that has

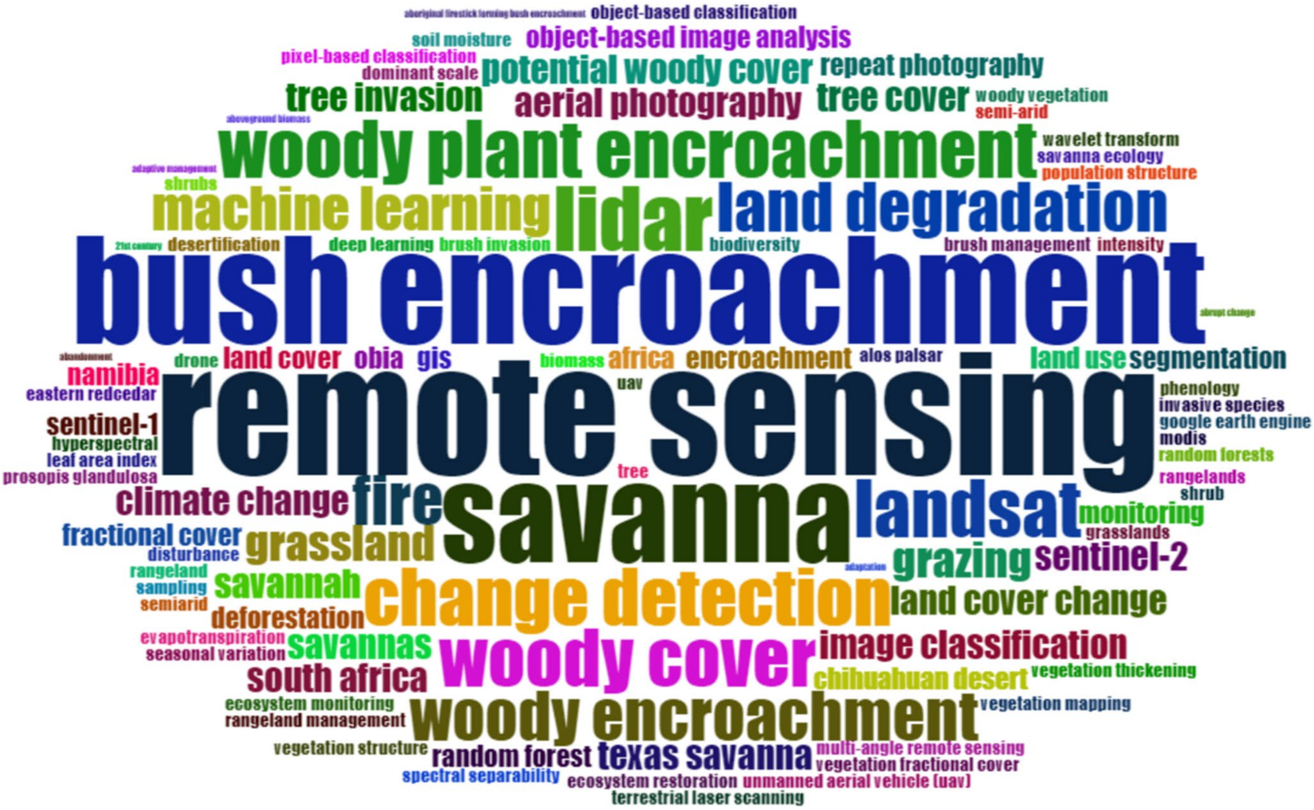

Fig. 4 Word cloud of authors' keywords on BE mapping using RS in grasslands and savannas for the survey period 1998 to 2022

been conducted in past (Pesta et al. 2018) and the direction future research will go (Mulay et al. 2020). Words such as RS, shrub encroachment, bush encroachment, and woody plant encroachment were the most used author's keywords. Remote sensing tools that were primarily used in mapping BE were "aerial photography", "LiDAR", "Sentinel-2", "Sentinel-1", "MODIS", "Landsat", "SAR". Methods that were used to map BE included "object-based image analysis", "pixel-based classification", "random forest", "spectral separability", "machine learning", etc. "Biomass", "vegetation structure", "phenology", "tree cover" etc. appeared as some parameters that have been researched on bush encroachment. Among the words written in small font were Unmanned Aerial Vehicle (UAV), drone, and hyperspectral, indicating that there is still a need for research that uses these RS platforms in mapping and monitoring bush encroachment.

Top 10 globally cited documents on bush encroachment mapping using remote sensing in grasslands and savannas

Table 4 shows the top 10 globally cited published documents on BE mapping using RS in grasslands and savannas over the survey period. The ranking of the published documents was based on the total citations (TC) in the survey period. Document citation by researchers shows the relevance of the research in a specific research field or the researcher's preference. An article with a high number of citations indicates that the research work has more relevance. In Table 4, the analysis showed that the most globally cited article was written by Laliberte et al. (2004) with TC of 427. This article used object-oriented image analysis method on aerial photographs and Quickbird satellite images to determine the increase in shrub encroachment. The second and third highly cited articles were written by Naito and Cairns (2011) and Hudak and Wessman (1998) with 163 and 149 TC, respectively. Naito and Cairns (2011) evaluated patterns and global shrub expansion in rangelands. Hudak and Wessman (1998) conducted Textural analysis of historical aerial photography to characterize woody plant encroachment in South African Savannas.

Discussion

Annual scientific trends

The results of this study revealed that the annual scientific production trends in bush encroachment mapping using

Table 4 Top 10 globally cited articles on bush encroachment mapping using remote sensing in grasslands and savannas

No.	Author		Year	Journal	TC
1.	Laliberte A. S.	Object-oriented image analysis for mapping shrub encroachment from 1937 to 2003 in southern New Mexico.	2004	Remote Sensing of Environment	427
2.	Naito A. T.	Patterns and processes of global shrub expansion.	2011	Progress in Physical Geography: Earth and Environment	163
3.	Hudak A. T.	Textural Analysis of Historical Aerial Photography to Characterize Woody Plant Encroachment in South African Savanna	1998	Remote Sensing of Environment	149
4.	Stevens N.	Woody encroachment over 70 years in South African savannahs: overgrazing, global change or extinction aftershock?	2016	Philosophical Transactions of the Royal Society B: Biological Sciences	141
5.	Browning D. M.	Woody Plants in Grasslands: Post-Encroachment Stand Dynamics	2008	Ecological Applications	115
6.	Mitchard E. T. A.	Woody encroachment and forest degradation in sub-Saharan Africa's woodlands and savannas 1982–2006	2013	Philosophical Transactions of the Royal Society B: Biological Sciences	92
7.	Hellesen T.	An Object-Based Approach for Mapping Shrub and Tree Cover on Grassland Habitats by Use of LiDAR and CIR Orthoimages	2013	Remote Sensing	89
8.	Brandt M.	Assessing woody vegetation trends in Sahelian drylands using MODIS-based seasonal metrics	2016	Remote Sensing of Environment	81
9.	Goslee S. C.	High-resolution images reveal the rate and pattern of shrub encroachment over six decades in New Mexico, U.S.A.	2003	Journal of Arid Environments	73
10.	Skowno A. L.	Woodland expansion in South African grassy biomes based on satellite observations (1990–2013): general patterns and potential drivers	2018	Global Change Biology	73

remote sensing in grasslands and savannas started in 1998 with one publication and thereafter increasing over the years and reaching a peak in 2022 with 19 publications. These results suggest that there has been an increasing interest in bush encroachment mapping using remote sensing in grasslands and savannas during the survey period with an average annual growth rate of 13.05%. The increase in publications in this field could be linked to the reported increased occurrence of bush encroachment worldwide (Deng et al. 2021; O'Connor et al. 2014; Eldridge et al. 2011). Due to the latter, countries are looking for reliable and accurate techniques, which can augment traditional techniques in evaluating the increased occurrence of bush encroachment. The increased availability of RS data enabled researchers to test if RS tools are a suitable method for mapping and monitoring bush encroachment. For that reason, remote sensing tools have been increasingly used in mapping bush encroachment in grasslands (Soubry and Guo 2022) and savanna ecosystems (Abdi et al. 2022) as researchers seek to understand patterns of bush encroachment and thereafter implement appropriate management strategies. In addition, remote sensing products are becoming more easily available at no purchase cost e.g. data from United States Geological Survey (USGS) Earth Explorer. Remote sensing platforms and the scope of their application are being improved and increasing meaning that more knowledge attained from mining the information from the images (through the use of machine learning algorithms) is increasing (Mashala et al. 2023).

Spatial distribution and most cited documents per country

The results revealed that USA, South Africa, Australia, and China were the most productive countries in terms of publications. The high output of research in these countries and institutions could be linked to the fact that these countries have immense grassland (Gang et al. 2015; Erfu et al. 2016) and savanna ecosystems (Fensham et al. 2005). These vast ecosystems are experiencing changes and countries want to monitor these changes in order to be able to manage them. For that reason, countries like China for example previously only relied on remote sensing data acquired by international satellites. However, China has advanced its research over the years and dedicated research on environmental monitoring utilising remote sensing data from its satellites (HJ-1 satellites) which they developed as a result of fast-tracking scientific and technological advancements (Li et al. 2020). The USA developed the Landsat programme (in 1972) which could monitor crops and vegetation (Mather n.d.) amongst others. Australia on the other hand has been utilising remote sensing data acquired by satellites such as Landsat for purposes of monitoring environmental degradation amongst others (Forster et al. 1987). Also, South Africa has developed microsatellites such as SumbandilaSat (Engel and Mostert 2006; Scholes and Annamalai 2006; Siyabona Africa 2009) which was meant to provide data for monitoring agriculture, land use mapping and monitoring water (Siyabona Africa 2009). Even though the SumbandilaSat is no longer operational, however, data obtained from this satellite still plays a role in environmental monitoring in South Africa.

The results also revealed no published documents in more than 50% of African, South American, Asian, and European countries. There can be various reasons for the limited participation of these countries. However, the limited participation of other African countries in this research could be linked to limited resources in acquiring remote sensing data, data storage (Amissah-Arthur and Miller 2002; Rowland et al. 2007) and limited resources in processing the big data. Also, Africa has little investment in remote sensing tools (Milsat Technologies 2021). Even though that is the case, studies have revealed that there are microsatellites that have been developed in the African continent (Ngcofe and Gottschalk 2013). The little to no appearance of these remote sensing platforms in published research could be that bush encroachment mapping research using these microsatellites has not been published or that these microsatellites are used for other purposes. This shows that there is a need for improvement in African countries in investing in devices and skills that can be used to download and process data that is already freely available so that research on bush encroachment with application of remote sensing in grasslands and savannas can be advanced.

Globally cited documents

Citation analysis is regarded as one of the standard tools and important determinants for assessing the impact of a published article (Li et al. 2023; Rejeb et al. 2022). It shows the assessment of the impact of published articles even though it may be predisposed to flaws such as citation bias, self-citation etc. (Sarli et al. 2010). In this study, more than 50% of the top 10 most cited articles used aerial photographs in mapping bush encroachment. The high-use of aerial photographs could be due to the fact that they were the first form of remote sensing that played a critical role in BE mapping research by providing a window into the past (Morgan et al. 2010). Other RS tools used by the top 10 most cited documents included Landsat, MODIS, Light Detection and Ranging (LiDAR) and Advanced very-high-resolution radiometer (AVHRR). High-frequency use of Landsat and MODIS could be attributed to their extensive coverage of data collection of the earth's surface and that they have been operational for an extended period. These sensors have been helpful in mapping bush encroachment even though Landsat was identified as not the most suitable for determining woody plant species' spectral and structural characteristics (Soubry and Guo 2022). The use of LiDAR in BE mapping could be due to its provision of height information for the woody plants (Zhao et al. 2021). (Hellesen and Matikainen 2013) noted that the additional structural characteristics detected by LiDAR to spectral characteristics of woody plants improved their classification.

Influential journals and keyword analysis

Academic journals are a source of information and knowledge. They distribute information, publish innovative ideas and techniques that work in a specific field. They also provide the status of research and the future of research (Childe 2006). Journals can be categorised as open access and subscription based. The Remote Sensing and Remote Sensing of Environment journals were the dominant publishing journal sources of bush encroachment mapping using remote sensing in grasslands and savannas in the survey period. The Remote Sensing and Remote Sensing of Environment journal are open access journals meaning that their published information is accessible without any cost and therefore reaches a wider audience. With these journals being open access indicates that they are good platforms to disseminate research relating to applications of remote sensing to map bush encroachment in grasslands and savannas. This is an advantage to readers in developing countries since they have limited resources. These journals have impact factors of 5.349 and 13.85, respectively. The impact factor of a journal can show the global influence of the journal (Zhang et al. 2017). These journals can be central in strengthening research in this field and influence the development of more research on the application of remote sensing in mapping bush encroachment in grasslands and savannas since they are the dominant publishers of this content. Both the journal of Remote Sensing and Remote Sensing of Environment focus on the publication of research covering the application of remote sensing tools in terrestrial and other environments. Since most of the published articles in the survey period were from developed countries, indicates that it is them who mostly publish in these journals because they have resources to publish. The publishing charges are a restriction to developing countries as it was evident from the limited publications. Even though that is the case, however, developing countries with limited resources e.g. those from Africa have published these journals.

The keywords of published documents are the words that authors select to communicate an article in their field (Corrin et al. 2022). Keyword analysis is based on the frequency of occurrence of particular words in the surveyed documents that authors have selected. They determine the important topics in the research and show developments and direction of research in that field (Chen and Xiao 2016). In this study, "remote sensing", "shrub encroachment", and "bush encroachment" were the most used keywords in articles dealing with BE mapping using RS in grasslands and savannas during the survey period. The frequent use of these words shows the historical and current role that remote sensing plays in mapping and monitoring of BE, which provides archive data (Cao et al. 2019). The results also showed a high occurrence of "Landsat", "Sentinel-2", "aerial photography", "Sentinel-1" and "LiDAR" as RS tools, which have been contributing to the research of bush encroachment. Landsat is one of the old satellites that have been long standing since 1972 and have an archive of data that is important in studying bush encroachment over a long time. The RS tools were useful in investigating aspects such as "phenology", "biomass", "population structure", "evapotranspiration", "change detection" etc. The authors' keywords "image classification", "object-based image classification", "spectral separability", "deep learning", "random forest", and "machine learning" have played a role in mapping and bush encroachment during the survey period. Classification techniques are the most prevalent techniques used in mapping bush encroachment as these are methods in which information about woody plants can be extracted. Authors' keywords such as "UAV", "drone", and "hyperspectral" appeared in low frequency because these RS tools have not been frequently used by researchers in bush encroachment research during the survey period. This indicates a lack of research studies utilising these remote sensing tools in mapping bush encroachment in grasslands and savannas. Therefore, future studies can explore these tools to improve bush encroachment mapping research. These findings are in agreement with those of Costa et al. (2023) who recommended further investigation of UAV in bush encroachment studies. Also, Madsen et al. (2020) recommended that UAV is a suitable tool to map grassland woody plants dynamics. These RS tools can be used in working towards addressing target 5 and 8 of SDG 15 and obtained information can be used in making decisions regarding monitoring and management of land degradation.

Conclusion

This study reviewed research trends of BE mapping using RS in grassland and savanna ecosystems using bibliometric analysis from 1998 to 2022. The study sourced published documents from Web of Science and Scopus. The assessment of published research was conducted to demonstrate the developments and progress of utilisation of remote sensing tools in mapping bush encroachment in grasslands and savannas. This study found increasing research on the application of remote sensing tools in mapping bush encroachment in grasslands and savannas during the survey period. However, most of the published documents were produced mainly by the first world countries and a few publications were from third world countries. Various RS sensors such as aerial and satellites have been widely explored. However, there was limited research on usage of sensors such as UAV and hyperspectral in BE mapping, especially in southern Africa. This then suggests a gap in which future research on BE mapping can exploit. The findings from this study will be vital to scholars, government institutions, and research institutions to strengthen their understanding, application, adaptation, and integration of remote sensing tools in the management and monitoring of bush encroachment. The findings of this study are important in the planning and management of bush encroachment and a revelation for scholars in those countries that had little or no contribution to this research and provide suggestions for future research. The limitations of this study were that this study focussed on studies that used bush encroachment and its synonyms as keywords. However, some scholars used words such as "bush encroachment" and "invasive species" as synonymous terms and such studies were excluded. Also, this study did not consider documents published in journals not affiliated with the selected databases. Therefore, further research could include other database and keywords, such as invasive species.

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Declarations

Conflict of interest The authors declare no conflict of interest.

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