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# Digital Image Processing for Land Use and Land Cover Mapping: A Literature Review

## *Processamento Digital de Imagens para Mapeamento de Uso e Cobertura da Terra: Uma Revisão de Literatura*

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**Abstract:** The objective of this article is to carry out a literature review on digital image processing and its application in land use and land cover mapping. The literature review used a hybrid, bibliometric and systematic approach. From a bibliometric perspective, the quantitative approach was valued, using Bibliometrix metrics, through the R software. For this research, the phrase Digital image processing for land use and land cover mapping was used. The systematic approach was carried out through qualitative and quantitative analysis of the variables: type of sensor, whether studies were carried out in rural or urban areas, the type of approach and the scale of analysis. The results revealed the mapping of 713 publications, including 324 and 389 from the Scopus and Web of Science databases, respectively, published from 1973 to 2022, the total period covered 49 years, excluding repetitions of 88 publications, which resulted in 625 publications. All 625 articles were analyzed, highlighting research in rural areas, the use of LANDSAT images and classification using classical methods.

**Keywords:** Remote sensing of the environment; Mapping of natural resources; Bibliometrix.

**Resumo:** O objetivo deste artigo é realizar uma revisão de literatura sobre o processamento digital de imagens e sua aplicação no mapeamento de uso e cobertura da terra. A revisão de literatura utilizou a abordagem híbrida, bibliométrica e sistemática. Sob a perspectiva bibliométrica foi valorizada a abordagem quantitativa, por meio de métricas do Bibliometrix, através do software R. Para esta pesquisa, foi utilizada a frase Digital image processing for land use and land cover mapping. A abordagem sistemática foi realizada através de análise quali-quantitativa das variáveis: tipo de sensor, se estudos foram realizados em área rural e urbana, o tipo de abordagem e a escala de análise. Os resultados revelaram o mapeamento de 713 publicações, dentre as quais 324 e 389 das bases Scopus e Web of Science, respectivamente, publicados de 1973 a 2022, o período total cobriu 49 anos, excluídas as repetições de 88 publicações, o que resultou em 625 publicações. Todos os 625 artigos foram analisados, destacam-se pesquisas em zona rural, o uso de imagens LANDSAT e classificação por meio de métodos clássicos.

**Palavras-chave:** Sensoriamento Remoto do ambiente; Mapeamento dos recursos naturais; Bibliometrix.

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## 1. Introduction

Digital Image Processing (DPI) techniques are recurrently being applied to land use and cover mapping (LUCM). DPI techniques allow for the extraction of information and also for the improvement of the visual quality of images in order to make them interpretable by a human analyst or by machine learning (FONSECA *et al*., 2009). This becomes relevant since land use and coverage configure data sources for analysis in geographic information systems that have been used for a wide range of geospatial applications, such as urban planning, geographic modeling, water resources, and transport, among others (AHMED *et al*., 2019). Consequently, LUCM enables the monitoring of natural resources, supervision of land development, and other applications for extracting high-precision and high-frequency information about changes on Earth (LIU *et al*., 2023). Furthermore, for Liangyun *et al*. (2023), LUCM, through the DPI, is on the list of main topics submitted to specialized journals between 2021 and 2022, representing 44.5% of submissions. Despite this, DPI techniques can be influenced by a number of factors, such as the type of sensor, spatial, spectral, radiometric resolution, and presence of aerosols and clouds (SAUSEN, 2005), which can have influence on land use and cover analyses.

The type of sensor, active or passive (MISRA, 2022), differs based on the source of Electromagnetic Radiation (REM) that the satellites have to generate the image. The active sensors produce their own source of REM, whereas passive sensors rely on an external source, which is usually the sun. Synthetic Aperture Radar (SAR) and Light Detection and Ranging (LiDAR) sensors are active methods of acquiring information and their added value, among other factors, arises from the fact that they provide the possibility of extracting information even in adverse weather conditions, such as with the presence of clouds (JIA *et al*., 2021), which dispenses some DPI techniques, for example, band filtering. Active sensors are used in various mappings without calibration for reflectance and can operate under cloudy conditions or at night (FITZGERALD, 2010). On the other hand, high-resolution and hyperspectral imaging are optical sensing approaches (JIA *et al*., 2021), therefore relevant for LUCM.

Images from passive sensors are strongly influenced by changes of the atmospheric conditions, including pollution, dust, clouds, and changing solar zenith angles, with the last two being the most influential (FITZGERALD, 2010). these images, however, come at a lower cost (FORBES *et al*., 2020). Sishodia *et al*. (2020) stated that the use of unmanned aerial vehicles, which are, for the most part, passive sensors, has increased considerably over the last decade and this is due to the cost of equipment for obtaining high-resolution images.

Regarding spatial, spectral, and radiometric resolutions, the influence of spectral confusion in large pixels stands out, due to the mixture of spectral responses from different classes (ZHOU *et al*., 2022). Besides this, DPI techniques favor the fusion of multispectral bands with panchromatic bands (PU *et al*., 2011; ANANDA *et al*., 2019), which improves spatial resolution. For Jia *et al*. (2021), instrument performance and preprocessing data results are the main factors that assist in acquiring high-precision surface reflectance data.

Despite the importance of considering the characteristics of the sensors, it has been observed that the free availability of numerous programs for LUCM, including artificial intelligence (AI) tools, favors DPI applications. Fonseca *et al*., (2009) and Renó *et al*. (2011) presented an analysis of Remote Sensing (RS) images using the Georeferenced Information Processing System (SPRING), which is a free technology made available by the Brazilian National Institute for Space Research (INPE). Recently, other technologies, also free, have been used, including Google Earth Engine (GEE) (LIMA *et al*., 2022; GXOKWE *et al*., 2022) and Software R (LEMENKOVA and DEBEIR, 2022; WANG *et al*., 2022). AI and machine learning techniques offer superior performance, accuracy, and efficiency in classifying satellite images and enable the processing of large volumes of data.

New technologies are coupled with the large number of geospatial databases that make RS data and information available free of charge, some of which have been around since the 1970s, such as the Land Remote Sensing Satellite (LANDSAT), which are incorporated by new tools, such as GEE. For Ravanelli *et al*. (2018) GEE features a dedicated high-performance computing infrastructure that allows researchers to easily and quickly access more than thirty years of free public data archives. In this sense, in addition to LANDSAT, the China-Brazil Earth Resources Satellite (CBERS) stands out, which has images made available free of charge by INPE. Thus, given the possibilities, the importance of the topic, and the analysis gap, this research aims to carry out a literature review on digital image processing and its application in LUCM.

## 2. Methodology

The literature review used the hybrid, bibliometric, and systematic approach (Figure 1), for the period between 1973 and 2022. From the bibliometric perspective, the quantitative approach was applied, through Bibliometrix metrics conducted in Software R. For this perspective, the phrase "Digital image processing for land use and land cover mapping" was used as the search string. The search was carried out through the Periodicals Portal of the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), through access from the Federated Academic Community (CAFe), the Scopus (Sco), and Web of Science (WoS) databases applied to the Title of the article, Summary, Keywords and Authors.

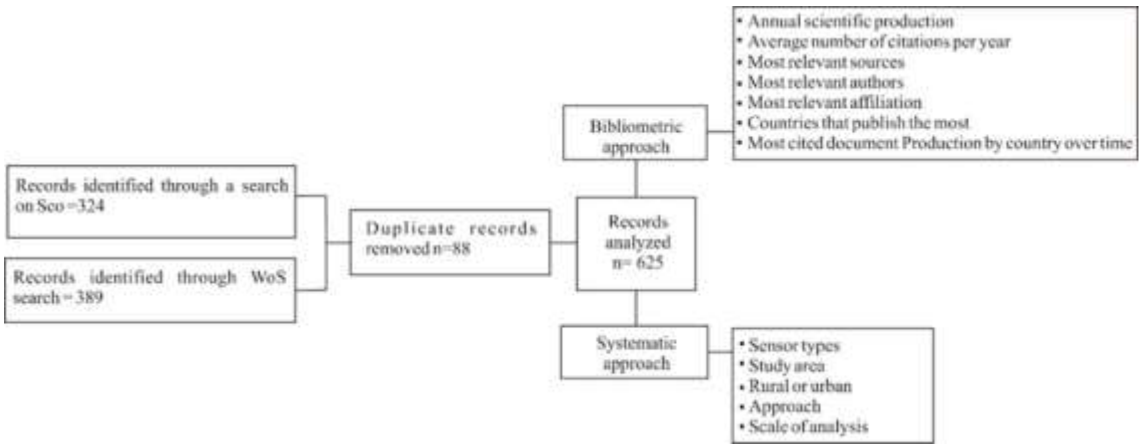


*Figure 1 – Summary of the applied methodology.*
*Source: Elaborated by the authors (2023).*

Following the methodological flow, from a systematic analysis perspective, the following criteria were evaluated: types of sensors, study area, whether rural or urban, type of approach (classical or machine learning), and the scale of analysis (local, regional, or global). The definition of such criteria occurred due to the large volume of articles mapped since all identified studies were selected for the systematic review.

The data generated by Bibliometrix were exported to an electronic spreadsheet where graphs and a map were created with the number of documents by country.

## 3. Results and discussion

Alongside the new technologies, there are a large number of geospatial databases that make RS data and information available without cost, some of which have been around since the 1970s.

*Bibliometric perspective*

Based on the 625 analyzed articles, it was observed that scientific publications on DPI for LUCM became relevant (grew approximately 5 times) at the end of the 1970s (Figure 2). Furthermore, the results suggest growth that fluctuates over time, however, there is a linear trend of increase.

According to Ferreira *et al*. (2008), the beginning of the use of orbital RS dates back to the first manned space flights in the 1960s and the launch, in 1972, of the Earth Resource Technological Satellites (ERTS-1), currently LANDSAT, and other orbital platforms (AGAPIOU and LYSANDROU, 2015; WANG *et al*., 2019). Until then, little had been published in magazines and conferences specializing in RS. According to Jensen (2016), much of the research in this area has been aimed at military purposes. According to Zhuang *et al*. (2013), generally speaking, RS research increased significantly over the past two decades. This also revealed that international research cooperation in RS has increased (ZHUANG *et al*., 2013).

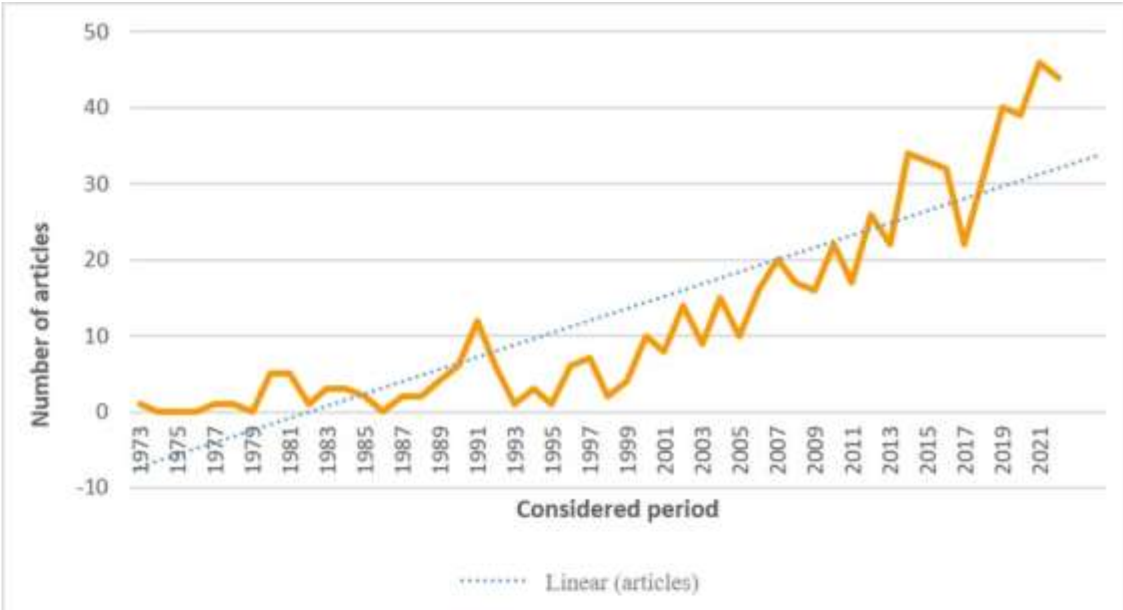


*Figure 2 – Evolution of annual scientific production.*
*Source: Elaborated by the authors (2023).*

Since the 1990s, with the launch of the first commercial satellites with high spatial resolution (1 meter), it has been possible to diversify research in RS (AGAPIOU and LYSANDROU, 2015). Additionally, to the passive RS programs (in the case of LANDSAT), the launch, in 1991, of the consolidation of the availability of images from active sensors, with the launch of European Remote Sensing (ERS-1) (FERREIRA, *et al*., 2008).

As a result of space programs, the development of DPI techniques, starting in the 1970s, boosted scientific publications related to land cover and land use mapping, in journals such as the IEEE Transactions on Geoscience and Remote Sensing and the Remote Sensing of Environment (SCHOWENGERDT, 2006). In addition, it refers to the activities of the Jet Propulsion Laboratory of the National Aeronautics and Space Administration (NASA) to present the first DPI techniques. Small (2021) supports this analysis by stating that, over the last 20 years, the proliferation of sensors and platforms in the public and private sectors, combined with the open data policies of NASA, the European Space Agency (ESA) and other national space agencies, have resulted in an increase in the availability of RS data. Regarding the analysis of the number of publications by periodicals, the Remote Sensing magazine stands out as the most relevant source (Figure 3). Remote Sensing is an open-access journal on the science and application of RS, published by the Multidisciplinary Digital Publishing Institute (MDPI) with indexing in several databases, including Scopus and Web of Science. Its Impact Factor has been above 5 in recent years (MDPI, 2023), therefore, it has high visibility. In second position appeared the Remote Sensing Open Access Journal (RS OAJ), which is a leading journal in the field of RS (ZHANG *et al*., 2019).

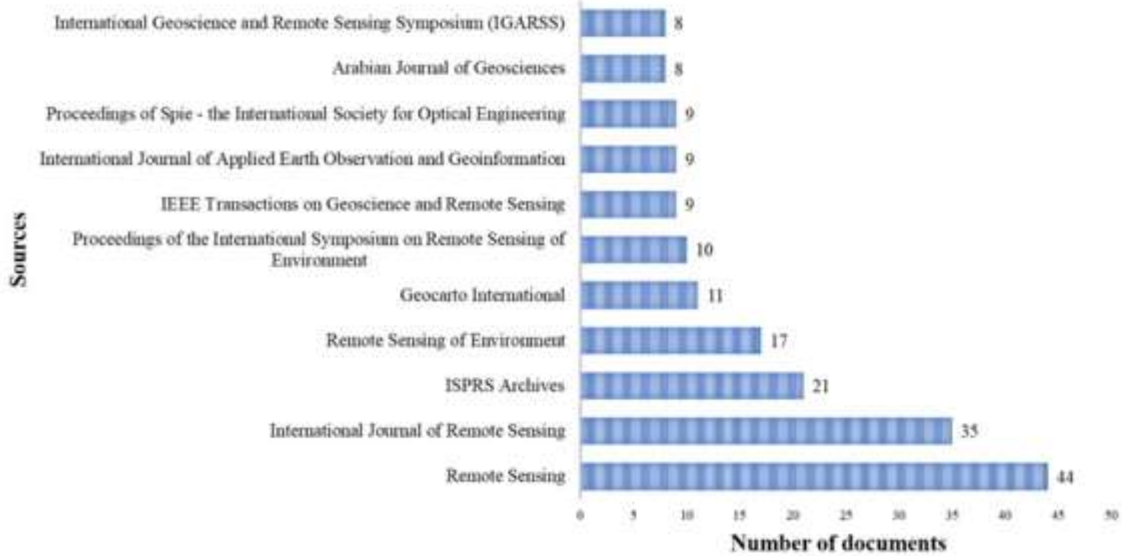


*Figure 3 – Most relevant sources (periodicals).*
*Source: Elaborated by the authors (2023).*

Additionally, the productions with the greatest publication impact were evaluated (Figure 4). In general, journals are evaluated in different ways, following a certain criteria, one of which is the impact factor.

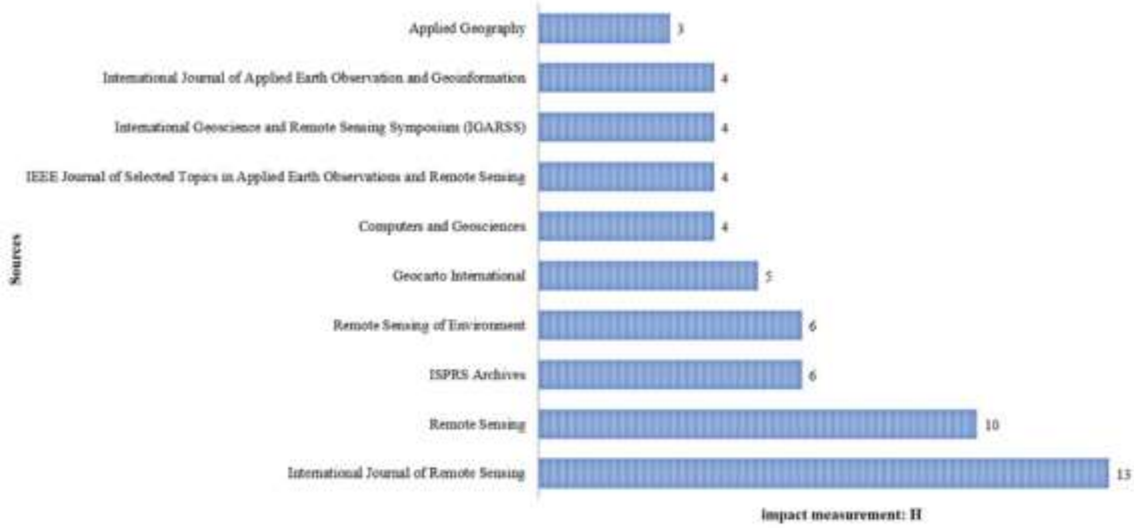


*Figure 4 – Productions with the greatest publication impact.*
*Source: Elaborated by the authors (2023).*

Here, the H impact was analyzed, which was described, since 2005, by Jorge E. Hirsch and which began to be recurrently used in scientific circles, as a way of measuring the productivity and impact of researchers (THOMAZ *et al*., 2011). Thus, the highlight is the International Journal of Remote Sensing, which also appeared in the research by Zhuang *et al*. (2013). The journal publishes international research on RS of the atmosphere, biosphere, cryosphere, and the surface, as well as the process of anthropization, and is an official journal of the Society for RS and Photogrammetry.

The most relevant authors, among the analyzed publications, are Li H and Pradhan Biswajeet (Pradhan B) (Figure 5). It was not possible to distinguish the name Li H from the results of this research, as this name appears for at least 6 different authors. This was also observed for authors with surnames Wang, Lee, Weng, and Zhuang.

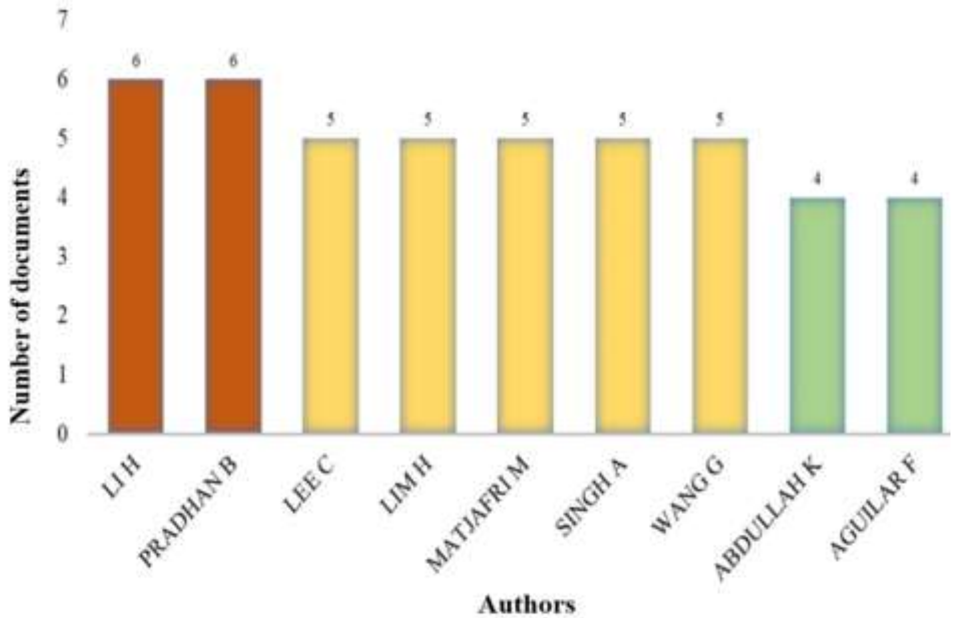


*Figure 5 – Authors with the highest number of published documents.*
*Source: Prepared by the authors (2023).*

Researcher Biswajeet Pradhan has 41,549 citations in Scopus and is the director of the Center for Advanced Modeling and Geospatial Information Systems (CAMGIS), at the University of Technology in Sydney, Australia. Pradhan is an internationally recognized scientist in the fields of geographic information systems, RS and DPI, geoinformatics, and machine learning, among other areas. Pradhan has innovated in his analyses, especially when he proposes the fusion of airborne LiDAR data with multispectral images from passive sensors to improve the extraction of information about land cover (SAEIDI *et al*., 2014). In another study, Pradhan contributed with analyses to improve the accuracy of urban mapping in built-up areas of skyscrapers through the orthorectification of images from passive sensors and LiDAR (PRADHAN *et al*., 2021), considered by the author himself as a trend in remote sensing studies.

Figure 6 reveals the list of most prominent authors based on the analysis of the H index. In this sense, the authors Fernando J. Aguilar; Manuel A. Aguilar; Raimundo Almeida-Filho, and A Belward.

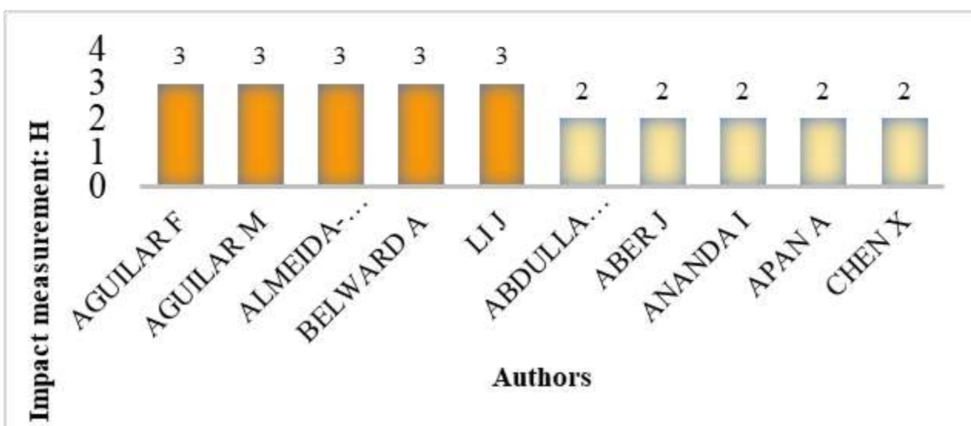


*Figure 6 – Most cited researchers based on H Index.*
*Source: Elaborated by the authors (2023).*

Researcher Fernando J. Aguilar works at the University of Almería, Spain, in the areas of geomatics, RS and computer science. His publications, in the area of use and coverage mapping, favor studies of agricultural areas (AGUILAR *et al*., 2014; NEMMAOUI *et al*., 2019). The researcher works in partnership with Manuel A. Aguilar, also from the University of Almería.

Researcher Raimundo Almeida-Filho is the only Brazilian on the list and works at INPE. His research mapped in this study is related to analyses in the Brazilian Amazon (ALMEIDA-FILHO *et al*., 2002; ALMEIDA-FILHO and CARVALHO, 2010; RENÓ *et al*., 2011). The researcher is part of a collaboration network with other researchers, and the analyses highlighted in this study were made possible through LANDSAT image processing.

Next, researcher Alan Belward is linked to the European Commission, at the Joint Research Center, Institute for the Environment and Sustainability, in Italy. The author holds 18,403 citations and has consolidated research in the area of RS, in which those on a global scale stand out. One of the most cited studies is the one mapping land use and land cover in Africa (STIBIG *et al*., 2007). Furthermore, the book entitled “Remote Sensing and Geographical Information Systems for Resource Management in Developing Countries” published by Springer in 1991 (BOCCO *et al*., 1991) stands out in this research.

As far as educational institutions are concerned, which are leading the way in RS research for MUCT, the University of Maryland has been the protagonist. Their pioneering work with NASA in image reception and processing began with the launch of LANDSAT in the 1970s. One of the outstanding programs is the Global Land Cover Facility (GLCF), which is an operational research and development project housed in the Department of Geographical Sciences at the University of Maryland.

Figure 7 shows scientific production by countries and thus, productivity in the United States of America, India, and Brazil stands out. The United States is one of the global pioneers in the development of programs to make RS data and information available to the world, as referred to in the ERTS-1 space program (FERREIRA *et al*., 2008). According to Melo *et al*. (2021), the USA's leading role was in all the major advances in the area of RS in the world and revealed technical-scientific discoveries that boosted new fronts of research. This happened thanks to favorable public funding that, for decades, enabled US companies to conduct technological leaps (MATOS, 2021).

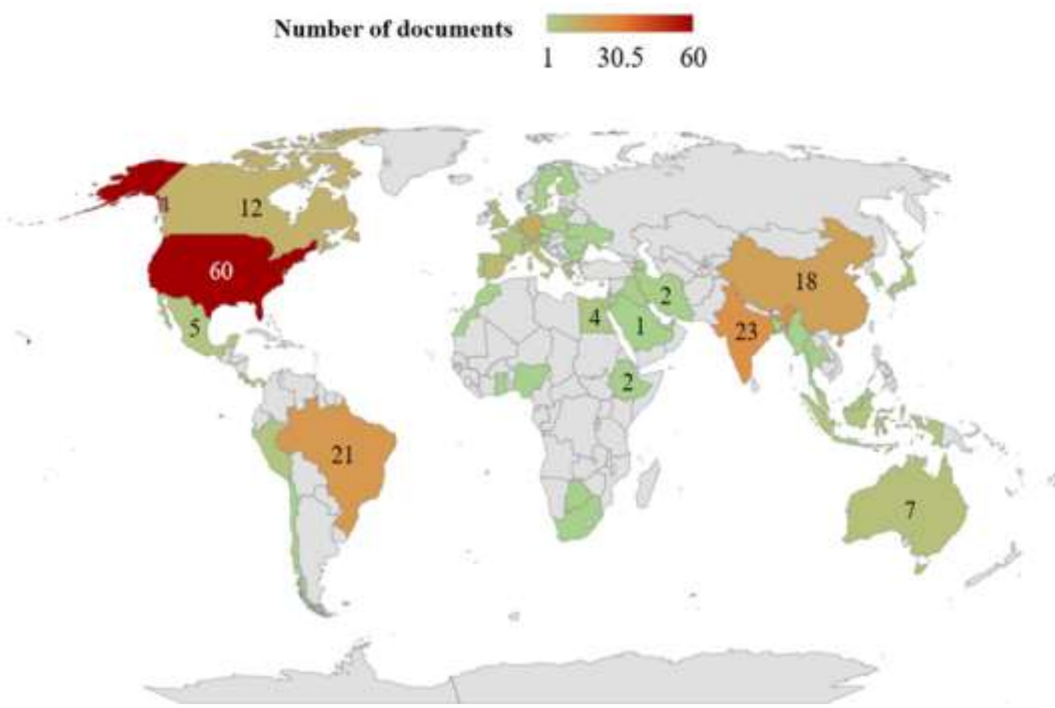


*Figure 7 – Number of documents mapped by countries.*
*Source: Elaborated by the authors (2023)*

Associated with investments in science, the USA attracts researchers from other parts of the world. This can be seen in the "brain drain" phenomenon, in which researchers are migrating to other countries in the search of better research conditions and remuneration, and this impact the number of works per country (YAN *et al*., 2020). This phenomenon can even cause an imbalance between the exit and entry processes of scientists in a given "national science system, as it brings losses to countries that are unable to retain their most qualified human resources" (VIDEIRA, 2013).

India's protagonism can then be explained from two perspectives. First, the country has a robust active RS orbital system, the Indian Remote Sensing Satellite (IRS), launched in the late 1970s. This program is the result from a partnership between India and Russia and it is considered to be one of the best examples of international cooperation in space (Indian Remote Sensing Satellite, 2023). An article published in 1983 already stated that the Indian remote sensing satellite (IRS) program constitutes an important step in the global program of using space technology for applications defined in India (NAVALGUND and KASTURIRANGAN, 1983). Ashutosh and Roy (2021) stated that the importance of the RS program and the numerous studies are associated with the fact that India is a country rich in biodiversity. On the other hand, urbanization and infrastructure development are putting considerable pressure on forests and these issues require an effective and efficient forest monitoring system (ASHUTOSH and ROY, 2021).

Thus, as it has happened in India, Brazil's prominence is attributable to an international partnership, but in this case with China. These countries have joined forces, which resulted in the creation of the China-Brazil Earth Resources Satellite (CBERS). Epiphanio (2009) stated that in the division of labor and costs, 30% would be covered by Brazil and 70% by China. For Silva and Benvenuto (2022), the development of the CBERS Program has made China and Brazil leading players in their regions in the field of scientific and technological innovation. Picoli *et al*. (2020) stated that CBERS is a powerful technology for mapping and monitoring Brazilian biomes. For the authors, CBERS images are effective in solving land use and cover issues to meet local and national needs related to landscape dynamics, including deforestation, carbon emissions, and public policies (PICOLI *et al*., 2020).

*Systematic perspective*

Generally, as for the types of satellite/sensors used in all documents, the predominance of the use of LANDSAT images was observed. As already mentioned, this RS program was the first launched into orbit for terrestrial resources (FERREIRA *et al*., 2008). Thus, the availability of this data since the 1970s is noteworthy. The program covers the entire world, with a satisfactory revision time and a number of bands that allow for varied processing. The name LANDSAT appeared in 13.12% of titles, abstracts, and or/keywords. It is important to note that, for some articles, the name satellite is not mentioned, in others, only the name of the sensors appears, for example, Thematic Mapper (TM), Enhanced Thematic Mapper (ETM), Operational Land Imager (OLI).

In this sense, 82 articles used LANDSAT data to map land use and cover. According to Wulder *et al*. (2022), since 1972, the LANDSAT program has continuously monitored the Earth, to now provide 50 years of digital, multispectral, medium spatial resolution observations. Still, according to Wulder *et al*. (2022), free and open access to LANDSAT data, enacted in 2008, was unprecedented for medium spatial resolution Earth observation data and substantially increased its use and led to a proliferation of scientific and application opportunities. In one of the applications surveyed in this review, LANDSAT images were applied to the MUCT of mountainous environments (YIN *et al*., 2022). For the authors, in mountainous environments, topography strongly affects reflectance due to illumination effects and projected shadows, which introduce errors into land cover classifications. The authors concluded that topographic correction remains necessary, even when analyzing a complete time series of LANDSAT images and including a digital elevation model in the classification (YIN *et al*., 2022). In another application, LANDSAT images were used in machine learning approaches to develop LUCM mapping (ALZAHRANI and KANAN, 2022). Thus, neural networks and/or Random Forest classifier were applied, and the authors revealed improvements in the land cover and use classification process, including the reduction in the complexity of the classification models for faster training times.

In addition to the above, of all remotely sensed data, those acquired by LANDSAT sensors played the most fundamental role in spatial and temporal scales. Given the 50-year record of LANDSAT data, mapping LUCM and derived surfaces into ecological models is becoming more common.

The surveys were more predominant in rural areas, with 28.32% compared to 3.36% in urban areas. The remaining studies were carried out in the urban/rural interface. These findings may be related to the fact that urban areas demand high spatial resolution data, given the dynamics of land cover by different targets. High spatial resolution data has been more expensive and widespread since the late 1990s. Despite this, images from LANDSAT, an OLI sensor, were used by Ali A. Khawfany *et al*. (2017) to differentiate different natural land covers and urban areas in Jizan, Saudi Arabia. Other studies have conducted mapping on a municipal scale, where the urban area is indicated in a generalized way (ALMEIDA-FILHO and CARVALHO, 2010; RENÓ *et al*., 2011; GAROFALO *et al*., 2015).

Regarding the RS approach, an increasing use of machine learning was identified (GE *et al*., 2020; ALZAHRANI and KANAN, 2022; SAVELONAS *et al*., 2022). However, the predominance of classical digital image processing approaches was identified (PU *et al*., 2011; ALMEIDA-FILHO and CARVALHO, 2010; AGUILAR *et al*., 2014). Although the use of machine learning has become a reality in DPI, empirical experience has revealed that its domain is still restricted, due to the need for knowledge of programming techniques.

The scale of analysis was predominantly local and regional. This result may have been influenced by the valorization and use of LANDSAT images, which for global analysis requires considerable computational effort, as several scenes would be necessary. Also, why LUCM is a predominant analysis at municipal scales (GAROFALO *et al*., 2015), river basins (JUNIOR *et al*., 2021; MARTINS *et al*., 2021), regions (ARNOUS and GREEN, 2015; MCCARTHY *et al*., 2020) and country (KHATAMI *et al*., 2020), which favors local and regional scales. Nevertheless, an example of a global approach is the work that has evaluated the distribution of the world's mangrove forests (GIRI *et al*., 2011). The result showed that the total area of mangroves in the year 2000 was 137,760 km² in 118 countries and territories in the tropical and subtropical regions of the world. Approximately 75% of the world's mangroves are found in just 15 countries, and only 6.9% are protected by the existing network of protected areas.

In general, from the survey research, it can be seen that DPI is divided into three basic stages: pre-processing, processing and post-processing. Pre-processing includes atmospheric corrections and calibrations. Processing includes all IDP methods, with classification predominating. Image classification is the main method that has been used by many researchers to produce thematic maps (AHMED *et al*., 2019). Thus, there was greater application of the Maximum Likelihood classifier, for traditional methods and Random Forest, for applications via machine learning. In post-processing, performance analyses of the classification process stand out. In this sense, only one study did not present an analysis of the accuracy of the classification process. According to Santos and Nunes (2021), for the classification technique to be replicated, accuracy/accuracy analysis is necessary. These are essential statistical parameters, which allow the reader to evaluate the 'quality' and limits of the work as a whole, therefore they should not be ignored.

## 4. Final considerations

This literature review can contribute to the understanding of the application of Digital Image Processing (DPI) to Land Use and Cover Mapping (LUCM). This is an unprecedented analysis of such an approach, as all articles found by the search strings used were analyzed. Furthermore, it was possible to conclude that:

- Scientific publications on DPI for LUCM became relevant (with an increase of approximately 5 times) at the end of the 70s. This was influenced by the availability of images and technological advances in processors;
- When considering the number of publications per journal, the Remote Sensing magazine stood out as the most relevant source for DPI research applied to LUCM;
- The researchers Biswajeet Pradhan and Fernando J. Aguilar stood out in this study. The first for publishing the largest number of articles and the second for the highest H index of its publications. In this sense, Biswajeet Pradhan has innovated the approach to integrating optical RS and LiDAR image analysis;
- The University of Maryland was the protagonist in research on RS and this is related to its research in partnership with NASA and the United States of America is the country with the largest number of articles published worldwide;
- LANDSAT images were the most widely used, which may have led to a predominance of analyses on a local and regional scale;
- The studies were predominant in rural areas, with 28.32% compared to 3.36% in urban areas. The remaining studies were carried out in the urban/rural interface;
- The classical approach to DPI is still the most common, despite the appreciation and increase in the number of machine learning applications. The prevalence of classic DPI methods may be related to the fact that machine learning has become a reality in DPI, but its dominance is still restricted.
- In general, it appears from the research consulted that the DPI is distinguished into three basic stages, pre-processing, processing, and post-processing;

- Finally, it is believed that this research can contribute researchers in positioning themselves in the current context of research on the use of RS for Land Use and Cover Mapping.

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