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Worldwide Research on Land Use and Land Cover in the Amazon Region

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Abstract: Land cover is an important descriptor of the earth's terrestrial surface. It is also crucial to determine the biophysical processes in global environmental change. Land-use change showcases the management of the land while revealing what motivated the alteration of the land cover. The type of land use can represent local economic and social benefits, framed towards regional sustainable development. The Amazon stands out for being the largest tropical forest globally, with the most extraordinary biodiversity, and plays an essential role in climate regulation. The present work proposes to carry out a bibliometric analysis of 1590 articles indexed in the Scopus database. It uses both Microsoft Excel and VOSviewer software for the evaluation of author keywords, authors, and countries. The method encompasses (i) search criteria, (ii) search and document compilation, (iii) software selection and data extraction, and (iv) data analysis. The results classify the main research fields into nine main topics with increasing relevance: 'Amazon', 'deforestation', 'remote sensing', 'land use and land cover change', and 'land use'. In conclusion, the cocitation authors' network reveals the development of such areas and the interest they present due to their worldwide importance.

Keywords: land cover; land use; Amazon; bibliometric analysis; knowledge mapping; cocitation; co-occurrence

1. Introduction

Land use and land cover (LULC) studies are at the forefront of global change research. Land use and land cover changes are applied in studies of deforestation, expansion, and the intensification of agriculture, energy footprints, and urban growth, among others; thus, these studies serve as a tool to determine its causes, consequences, and impacts on the environment [1–5]. The results of this research can help improve the management of natural resources in such a sustainable way as to satisfy the needs of current and future generations [6–8].

LULC have a robust intrinsic relationship and can often be misunderstood and even confused. Land cover represents the terrestrial surface of the earth, essential for many biophysical processes in global environmental change [9]. It indicates the type of surface coverage of the earth, such as surface waters biota, soil, and human infrastructure [10].

Land cover characterization includes a fundamental aspect in the managing of natural resources, environmental modelling, and geographical distribution of sites where animal and/or plant communities live [11,12]. Maps are a useful tool for indicating and visualizing land cover.

On the other hand, land use exposes the purpose for which humans exploit land cover. Land use involves altering the earth's biophysical attributes and revealing the purpose of this alteration [13]. Consequently, land use is related to land management, and it refers to how human beings use soil, water, and vegetation to obtain their goods. The irrigation systems of crops in drylands, and the displacement of forests for agricultural activities are clear examples of land use [10]. In contrast with land cover, land use is not as easy to map. For example, when observing pasture cover, it is almost impossible to confirm whether it is used for raising cattle or goats unless we validate the mapping with field data or use very high spatial resolution data [14].

Historically, agriculture has represented one of the most significant natural land cover changes, emphasizing the need for proper land use planning, given the environment impact caused by this anthropic activity. Consequently, LULC analysis must understand the human–environment dynamic and its drivers, scales, and footprints [15]. In addition, land use has an impact on climate change. This impact is often times associated with carbon emissions as a result of deforestation, loss of carbon absorption, and methane emissions caused by the flooding of large areas of forest during the implementation of hydroelectric dams, among other elements [4,16,17]. This does not account for the loss of biodiversity and environmental services also caused by land cover changes [18,19].

The Amazon comprises the world's largest and most diverse region of tropical forests [20], playing an essential role in the conservation of biodiversity, climate, and regional hydrology [21]. The western Amazon is one of the most biodiverse regions on the planet. It is home to different flora and fauna species, as well as to several Indigenous communities [22,23]. Deforestation presents as one of the greatest environmental threats to these species and communities [24].

Despite its extensive natural wealth and its importance guaranteeing global climate stability, constant changes in coverage and land use, mainly caused by the replacement of primary forest with pasture, have negatively impacted this territory [25–28]. Part of the Amazon rainforest has been lost due to deforestation for agricultural use, causing significant changes to its ecosystem [29,30].

Tropical forests are vulnerable to threats or pressures to their biodiversity and ecosystem service, which represents an impact on environmental components [31]. Deforestation can be classified as a direct threat to biodiversity [32]. In the Amazon, this is mainly caused by agricultural expansion, logging, land occupation, and infrastructure projects. The devastation of tropical forest areas tends to follow a familiar pattern. First, logging companies open paths around them, starting from highways to places where there are valuable trees. Second, as commercial timber runs out, the companies seek new areas to extract wood. Third, the now open roads are used by farmers, who seek to convert the forest into pasture, while commercializing the remaining wood. Finally, the population in the area causes fires as a way to manage the pastures, thus consolidating themselves in extensive low-production livestock areas [33,34].

Another activity that motivates tropical forests' deforestation is mining and oil extraction [35–37]. The development of these industries has caused negative environmental and social impacts, including deforestation associated with the construction of access roads, drilling platforms, and natural resource exploration [22]. In addition, there is a series of social and economic factors that contribute to the creation of new threats [32]. The contributing factors are associated with the increase in the insertion level of countries into the global market, making the Amazon increasingly more attractive for the exportation of its primary products, such as mineral, agricultural, and livestock commodities [33,38].

The Amazon has been the target of several studies, including terrestrial biogeochemistry analysis adjusted to climate models [39], LULC changes through the use of remote sensing [40], and the relationship between malaria (tropical diseases) and deforestation [41]. Other groups of research examine the generation of public policies to reduce deforestation rates in tropical forests [42], the management of possible areas for species conservation through species distribution models [43], forest fragmentation [44–46], species as an indicator of forest recovery [47], and the identification of species not yet catalogued [48,49]. The variety of scientific production of the region merits a bibliometric study that will complement all of the prior research with a focus on LULC.

A bibliometric analysis allows for the identification of emerging research areas within a subject and facilitates collaboration between institutions. Moreover, it is a tool that allows researchers to identify the groups of peers with the most significant influence, while showing the evolution of their publications over time [50]. Bibliometric methods are based on the processing of bibliographic information and allow for the mapping of the structure that exists within fields of study, while evaluating the performance of authors and institutions [51].

With the use of bibliometric methods, such as citation, cocitation, bibliographical coupling, coauthor, and coword analysis, we seek to answer the question: How has the structure of LULC and LULC change transformed during the Amazon's development over time?

Considering the Amazon as a place of great importance due to its biodiversity as well as a its status as a remaining forest frontier, a study is necessary to determine the main changes in LULC in the region, which has experienced various environmental alterations. The aim of this study is to carry out a bibliometric analysis of 1590 articles indexed in the Scopus database by using Microsoft Excel and VOSviewer to determine the intellectual structure of LULC and LULC change at the Amazon Region.

2. Materials and Methods

2.1. Geographical Location

The Amazon region, located in the north of South America (Figure 1), is shared by nine countries, Bolivia, Brazil, Colombia, Ecuador, Guyana, French Guiana, Peru, Suriname, and Venezuela. It stands out for its biological diversity and for being the largest continuous tropical forest in the world. It offers goods and services to the ecosystem, such as pollination and cultural and landscape provisioning. It also captures carbon from the atmosphere, establishes the water balance in the Amazon river system, and intervenes in the climate and air chemistry [18,19,52].

2.2. Methods—Data Processing

Systematic studies include rigorous techniques that allow for the replication of scientific procedures in order to reduce bias through a rigorous investigation of the publications reviewed [53]. Similarly, bibliometric studies encompass a strict process, endorsing the data used and providing a broad understanding of the area investigated [54,55].

Bibliometric analysis was initially considered as "applying mathematical and statistical methods to books and other media of communication" [56]. Currently, it is considered a research field that identifies patterns of a scientific discipline by analyzing its production and performance according to authors, countries, institutions, and prominent journals [57–59]. These studies facilitate the understanding of the intellectual structure related to a topic [60]. Bibliometric analysis is complemented with bibliometric maps, thus allowing for the visualization of the structure and its various connections with other academic disciplines [61,62].

Bibliometric studies have contributed to the academic world, including various fields of knowledge such as business and management [63–65], sustainability [66,67], education [68], and Earth sciences [69,70].

The systematic process used to carry out the bibliometric analysis and the construction of the bibliometric maps is presented in Figure 2: (i) Search criteria, (ii) Search and document compilation, (iii) Software selection and data extraction, and (iv) Data analysis.

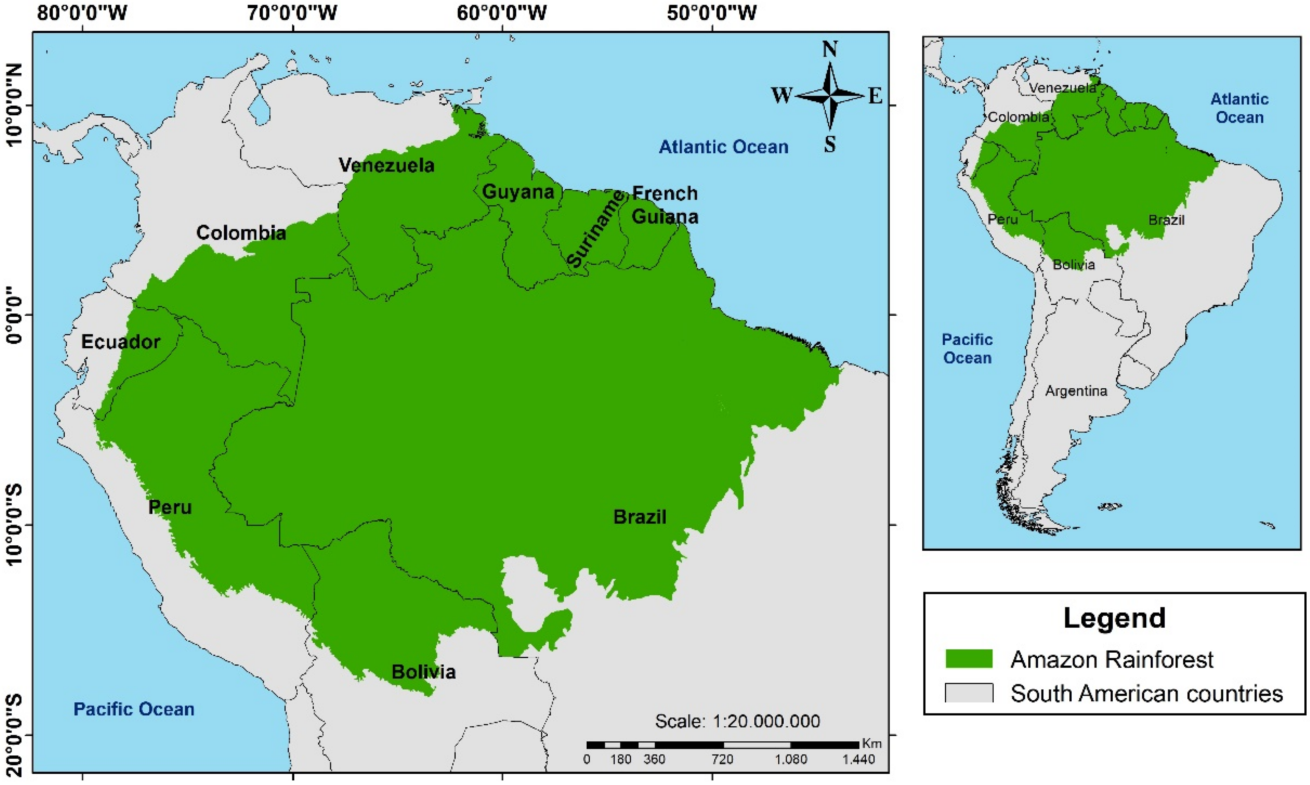

Figure 1. Study area location: Amazon Rainforest.

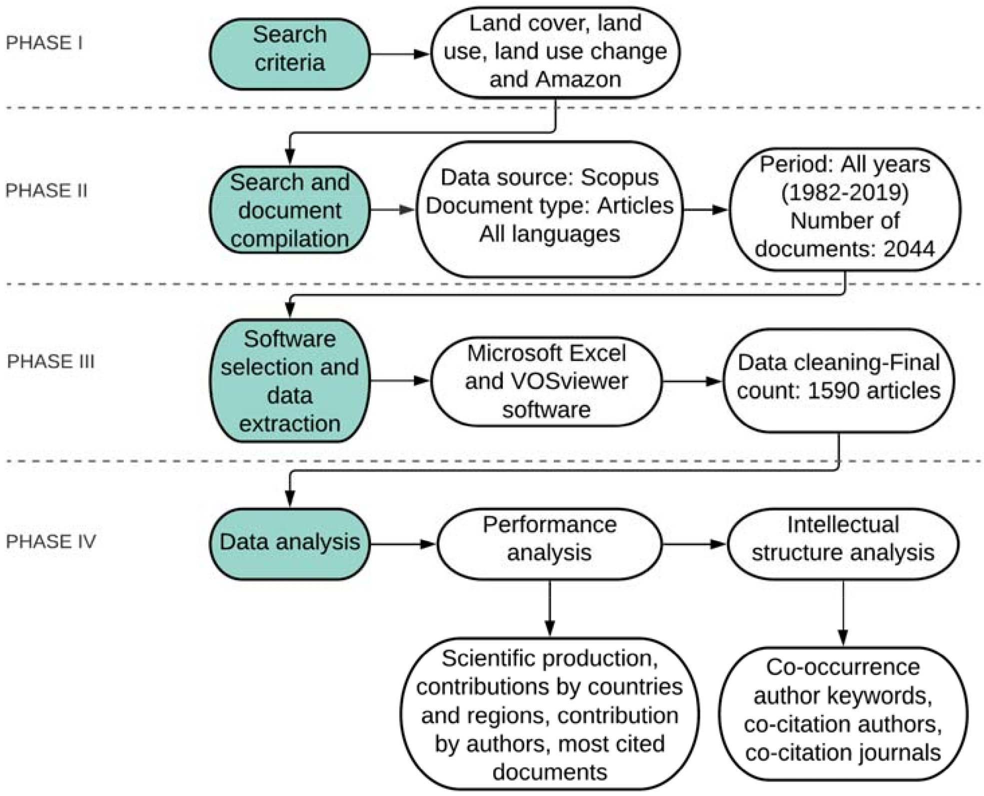

Figure 2. Methodological scheme.

2.2.1. Phase I: Search Criteria

The present study seeks to analyze the intellectual structure of the LULC in the Amazon region through a bibliometric analysis. This analysis initially requires identifying the field of study, so it is necessary to use descriptors to define its structure. For this purpose, land cover is considered a descriptor of the earth's terrestrial surface, specifically of its biophysical cover, which contains dominant biotic and abiotic groups [11,12]. For its part, land cover change makes it possible to identify land management. At the same time, land use reveals what motivated the alteration of the land cover, and it refers to how humans use natural resources, as well as the characterization of the soil surface [71]. These terms are key concepts to understand the relationship between human beings and the environment [72]. In the analysis of this field of study, the terms "land cover", "land use", and "land-use change" were used focusing on the Amazon region.

2.2.2. Phase II: Search and Document Compilation

The search was carried out on 27 July 2020 and was based on obtaining information through the Scopus scientific database, a base of scientific literature with broad information in various fields of knowledge [55,60,73].

The search was based on key terms that acted as descriptors of titles, abstracts, and keywords. Boolean operators were used, obtaining 2044 documents in the initial search. During the process, some exclusionary and inclusionary criteria were applied; for the first, the year 2020 was restricted due to not all documents being available in the database at the time of this study, resulting in 1941 documents that matched this criterion. In terms of inclusionary criteria, the search considered articles in all languages [70], obtaining 1604 documents. From this search, records that did not have complete information were removed, obtaining 1602 articles.

The search equation was defined as (TITLE-ABS-KEY ("land cover") OR TITLE-ABS-KEY ("land use") OR TITLE-ABS-KEY ("land use change") AND TI-TLE-ABS-KEY (amazon)) AND (EXCLUDE (PUBYEAR, 2020)) AND (LIMIT-TO (DOC-TYPE, "ar")) AND (EXCLUDE (LANGUAGE, "Undefined")).

2.2.3. Phase III: Software Selection and Data Extraction

The information collected from the database was downloaded as a comma-separated values (CSV) file, with information on authors, titles, years, journals, and languages. This information was analyzed and reviewed using Microsoft Excel. Incomplete data and duplicate records were detected and labeled as registry errors that should be erased [74,75]. In total, 12 records were discarded, obtaining 1590 articles.

The construction of the bibliometric maps was completed using the VOSviewer software (Leiden University), which allowed for the visualization of the study field's structure through a two-dimensional bibliographic network [76]. This software has been applied in different subjects, including business and management [68,77–80], the environment [81–83], medicine [84–86], and Earth sciences [87–89].

2.2.4. Phase IV: Data Analysis

Two approaches were combined: (i) the analysis of the performance of scientific production and (ii) the analysis of bibliometric maps [61,90]. The first is related to assessing the impact of the researchers' publications, countries, and affiliations involved [91]. The second corresponds to bibliometric mapping, the graphic representation of the study area to visualize the structure, topics, and research topics, as well as the existing relationships with other disciplines, using co-occurrence keyword analysis, cocitation authors, and cocitation journals [51].

3. Results

3.1. Performance Analysis

3.1.1. Analysis of Scientific Production

Figure 3 shows the distribution of the publications across time, starting from 1982 and divided by decades, according to the database. The intellectual structure presents 1590 articles, of which 1494 were cited, with a total of 57,305 citations. The first article was titled "Amazon Basin soils: management for continuous crop production", published by Sanchez et al. [92] in the journal *Science*, cited 172 times. The search showcased a significant growth in scientific production starting in 1992. In addition, the last decade (2010–2019) seems to have relevant representation, with more than 60% of the production of academic literature.

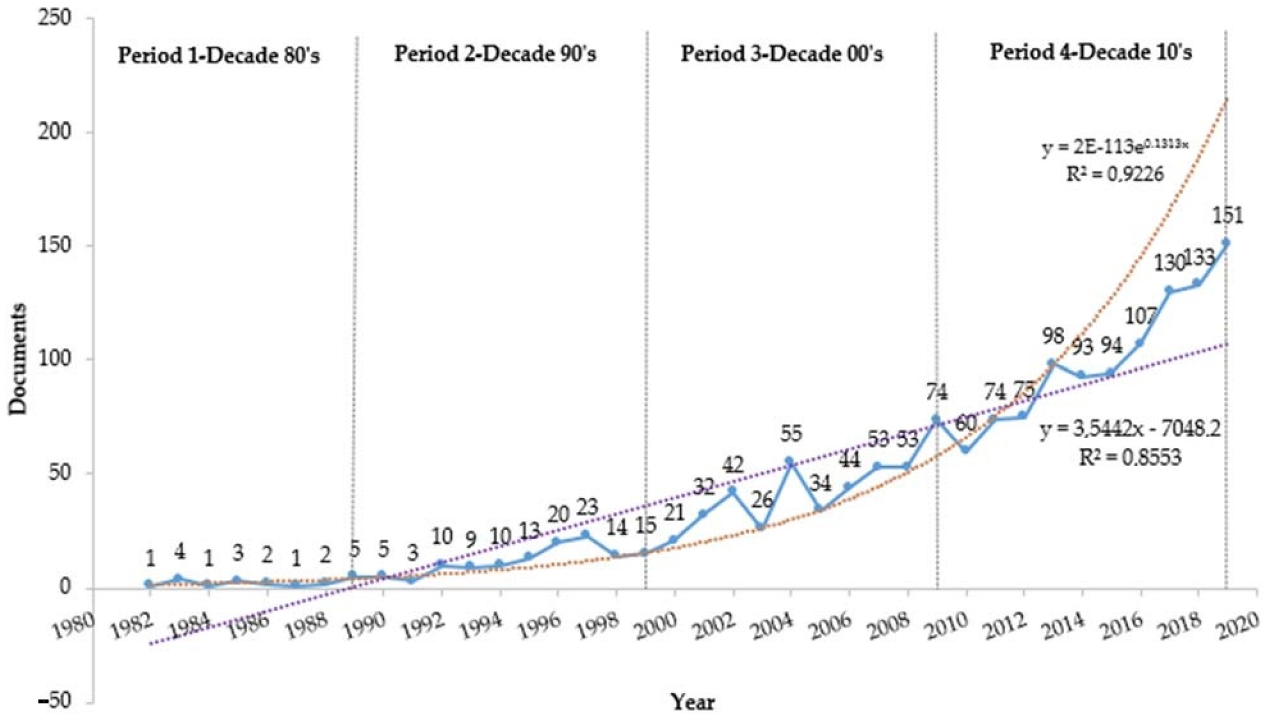

Figure 3. Evolution of scientific production on LULC in Amazon Region.

During the evaluation of the scientific production development, Price's exponential growth law was used [93,94]. The equation $y = 3.5442x - 7048.2$ corresponds to a linear fit with a coefficient of determination $R^2 = 0.8553$, while the equation $y = 2E - 113e^{0.1313x}$ corresponds to the exponential fit with a coefficient of determination $R^2 = 0.9226$. It is important to note that the value R^2 is higher in the exponential fit, which models the data by 92%, compared to the linear fit, which fits the data by 85%.

- Period 1—Decade 1980s: The first period has 19 publications that represent 1.19% of the total articles. The most cited article was published by Vörösmarty et al. [95] in the journal *Global Biogeochemical Cycles* and had 259 citations. The article studies the construction of a water balance and transport model to provide information on soil moisture, evapotranspiration, runoff, river discharge, and floodplains. During this period, studies related to deforestation [96], hydrobiogeochemistry [97], biogeochemistry [98], radar analysis [99], ecological analysis [100], and rainforest LULC change [101] were also presented.
- Period 2—Decade 1990s: The second period has 122 articles, representing 7.66% of the total articles. The most cited article was published by Adams et al. [102] in the journal *Remote Sensing of Environment* with 631 citations. The article deals with Landsat

images classification to determine land cover, in which techniques of spectral fractions of shadow, soil, and vegetation were applied. In addition, during this period, studies related to carbon storage and dynamics [103,104], deforestation [105,106], LULC [107,108], LULC change [109], and ecotourism and conservation [110] were presented.

- Period 3—Decade 2000s: The third period produced 434 articles that represent 27.26% of the total sample size. The most cited article was published by Feddema et al. [6] in the journal *Science*, with a total of 660 citations. The article addresses LULC changes. It reveals how agricultural expansion causes climate change in the Amazon associated with factors that influence the Monson and Hadley circulations of tropical climates. Additionally, during this period, studies related to biodiversity [111], agriculture [30], cloud cover [112], flood dynamics [113], effects of soil fertility [114], remote sensing [115,116], and LULC [117,118] were presented.
- Period 4—Decade 2010s: The fourth period presents 1015 articles and represents 63.76% of the sample size. The most cited article was published by Asner et al. [119] in the journal *Proceedings of the National Academy of Sciences of the United States of America*, with 410 citations. The article addresses the mapping of carbon stocks and emissions, indicating the determinants of forest carbon density. The authors' results revealed that emissions from LULC changes accounted for 1.1% of the region's carbon, and deforestation increased emissions by 47%. During this period, studies related to agriculture [120], fire mapping [121], deforestation [122], land-use change [123], biological diversity [124], land management [125], drought–fire interactions [121], LULC change [126], and vegetation dynamics [127] were presented. This decade highlighted a great interest in the scientific community, with a high quantity of publications produced compared to previous decades.

3.1.2. Regional and Country Contribution

Table 1 shows the 15 countries that have made the most outstanding contribution to the study subject, led by Brazil with 920 articles, followed by the United States with 737 articles and the United Kingdom with 162 articles. Brazil and the United States cover the most significant number of publications and citations. In the South American context, Brazil, Colombia, Peru, Ecuador, and Bolivia have contributed 1089 articles, receiving 38,588 citations. North America, including the United States and Canada, has contributed 799 articles receiving 39,241 citations. On the other hand, the European continent, represented by the United Kingdom, Germany, France, the Netherlands, Sweden, and Spain, has published 531 articles receiving 18,656 citations. This reveals that America, the continent where the Amazon region is located, presents the highest contribution in terms of publications.

Table 1. Top 15 countries according to number of publications.

Rank	Country	Region	Documents	Citations
1	Brazil	America	920	33,462
2	United States	America	737	37,429
3	United Kingdom	Europe	162	6727
4	Germany	Europe	115	3463
5	France	Europe	105	3037
6	Netherlands	Europe	64	3371
7	Canada	America	62	1812
8	Colombia	America	55	1835
9	Peru	America	54	1779
10	Sweden	Europe	48	1378
11	Australia	Oceania	42	1905
12	Ecuador	America	37	879
13	Spain	Europe	37	680
14	Indonesia	Asia	31	865
15	Bolivia	America	23	633

To have a better understanding of the collaboration that exists among each country, the VOSviewer software was used to obtain a network map, where each node represents a country. Figure 4 shows the collaboration network between countries. The network has 62 nodes or items, 10 clusters, and a link of 1375 with a total strength of 758,621. Brazil has a strong link with the United States (link strength 170,436), the United Kingdom (link strength 38,260), Germany (link strength 29,601), Canada (link strength 11,753), France (link strength 21531), the Netherlands (link strength 15,684), and Sweden (link strength 12,419), indicating a significant coauthorship between them. However, it should be noted that Brazil also presents authorship in conjunction with Asian countries such as China (link strength 3758); with Oceanian countries such as Australia (link strength 8723); with African countries such as Tanzania (link strength 226); and with other South American countries such as Colombia (link strength 7862), Peru (link strength 6710), and Ecuador (link strength 3959).

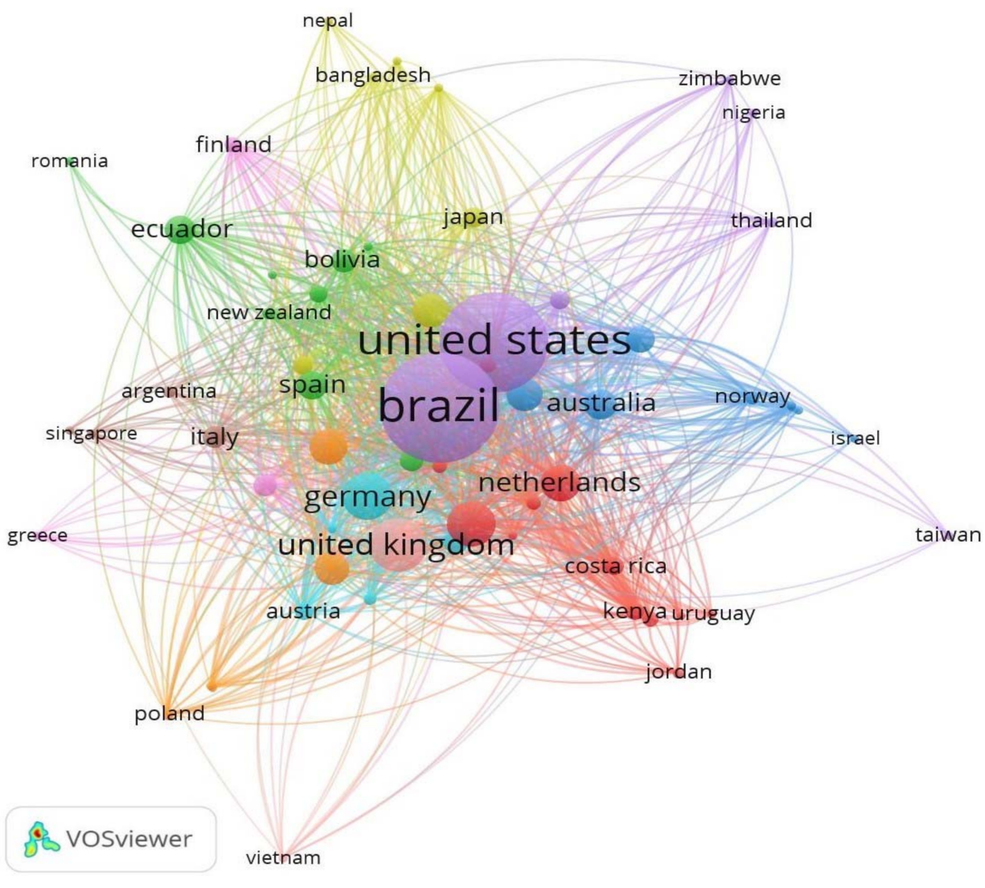

Figure 4. Countries network.

Among the countries that form part of the Amazon Region, Brazil has contributed with studies related to drought–fire interactions [121], microbial communities from soil under agricultural management [128], and environmental issues related to the expansion of sugar cane [129]. Bolivia's contributions include studies about the differences between species-diverse natural savannas and other vegetation classes with a dominant presence of grasses [130], grass distributions after selective logging [131], and the dynamics of farm development [132]. Colombia deals with studies of patterns and causes of ecosystem diversity, deforestation, and fragmentation [133], as well as land use and causes of deforestation [134,135]. Ecuador presents studies related to the design and implementation of an agent-based model used to simulate land-use change [126], identification of species conservation areas [43], and the evaluation of indicators of soil quality by land-use change [136]. Guyana's studies focused on a regional climate model to evaluate deforestation's impact [137]. French Guiana deals with a study of a times series of river water height by satellite radar [138]. Peru's studies focus on mapping land use planning in Indigenous territories [139], determining different types of vegetation [140], and the quantification of deforestation caused by artisanal-scale gold mining [141]. Venezuela has participated in studies related to the effects of shifting cultivation in the recovery of secondary forests [142], the nitrogen contents of rivers [143], and the evaluation of the changes in tree species after shifting cultivation [47].

3.1.3. Authors Contribution

Table 2 indicates the 15 principal authors who have made the most significant contributions to the scientific production. In a general context, 4240 authors related to land cover and use in the Amazon were presented. Even though the articles by Perz S.G. are predominant in the research field, the most influential articles correspond to the researcher Nepstad D.C with 25 documents and 3076 citations and the researcher Davidson E.A. with 24 documents and 2773 citations. Regarding the h-index, the authors Asner G.P. (105), Davidson E.A. (87), and Nepstad D.C. (63) can be considered the researchers with the most significant impact in their respective academic fields. It is worth mentioning that eight researchers from the top 15 belong to the United States, followed by five researchers affiliated with Brazil.

Table 2. Top 15 most-cited authors.

Author	Country	Affiliation	Intelectual Structure		Global Publication		H-Index
			Articles	Citations	Articles	Citations	
Perz S.G.	United States	University of Florida	31	1208	93	2807	28
Cerri C.C.	Brazil	Universidade de Sao Paulo	29	1707	224	10,013	59
Shimabukuro Y.E.	Brazil	Instituto Nacional de Pesquisas Espaciais	28	1873	236	6725	39
Moran E.	United States	Michigan State University	27	1545	150	12,948	47
Walker R.	United States	University of Florida	26	1701	86	3680	35
Asner G.P.	United States	Arizona State University	25	2507	549	46,763	105
Barlow J.	United Kingdom	Lancaster Environment Centre	25	1878	190	10,492	53
Cerri C.E.P.	Brazil	Universidade de Sao Paulo	25	1004	188	5304	42
Nepstad D.C.	United States	Earth Innovation Institution	25	3076	122	17,392	63
Davidson E.A.	United States	University of Maryland Center for Environmental Science	24	2773	223	31,820	87
Neill C.	United States	Woodwell Climate Research Center	23	1489	136	6718	40
Soares-Filho B.S.	Brazil	Universidade Federal de Minas Gerais	22	1299	109	8075	41
Brondizio E.S.	United States	Indiana University Bloomington	21	1261	118	7825	38
Gardner T.A.	Sweden	Stockholm Environment Institute	21	1633	125	11,012	52
Martinelli L.A.	Brazil	Universidade de Sao Paulo	19	1074	239	15,997	61

3.1.4. Frequently Cited Documents

The most frequently cited documents were analyzed in order to identify their impact in the field of study [144,145]. Table 3 shows the top 15 most frequently cited articles, receiving 7110 citations, equivalent to 12.41% of the total citations. Within the top 15, the article published by Feddema et al. [6], whose primary author is affiliated with the University of Victoria (Canada), stands out. This article addresses the changes in land cover and is followed by Davidson et al. [146], whose primary author is affiliated with the University of Maryland Center for Environmental Science (United States). The article studied the variation of the water content present in the soil at the eastern zone of the Amazon basin. It examines carbon dioxide emissions from forests and cattle pastures. The third article within the top 15 is Barlow et al. [111], whose primary author is affiliated with the Lancaster Environment Center (United Kingdom). The article discusses the conservation value and plantation forests of 15 taxonomic groups.

Table 3. Top 15 most-cited articles.

Rank	Author	Article	Citations
1	Feddema et al. [6]	Atmospheric science: The importance of land-cover change in simulating future climates	660
2	Davidson et al. [146]	Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia	640
3	Barlow et al. [111]	Quantifying the biodiversity value of tropical primary, secondary, and plantation forests	633
4	Adams et al. [102]	Classification of multispectral images based on fractions of endmembers: Application to land-cover change in the Brazilian Amazon	631
5	Morton et al. [30]	Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon	600
6	Houghton et al. [147]	Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon	545
7	Nepstad et al. [148]	Inhibition of Amazon deforestation and fire by parks and indigenous lands	484
8	Saatchi et al. [149]	Distribution of aboveground live biomass in the Amazon basin	414
9	Asner et al. [119]	High-resolution forest carbon stocks and emissions in the Amazon	410
10	Houghton et al. [150]	The spatial distribution of forest biomass in the Brazilian Amazon: A comparison of estimates	377
11	Trenberth et al. [151]	Atmospheric moisture recycling: Role of advection and local evaporation	367
12	Macedo et al. [120]	Decoupling of deforestation and soy production in the southern Amazon during the late 2000s	342
13	Tian et al. [103]	Effect of interannual climate variability on carbon storage in Amazonian ecosystems	340
14	Van Der Ent et al. [152]	Origin and fate of atmospheric moisture over continents	336
15	Trumbore [104]	Comparison of carbon dynamics in tropical and temperate soils using radiocarbon measurements	331
		SUM OF TOP 15 CITATIONS	7110
		TOTAL CITATIONS (1590 ARTICLES)	57,305

3.2. Analysis of the Intellectual Structure

3.2.1. Co-Occurrence Author Keyword Network

The author co-occurrence keyword analysis was based on using words to form relationships and build a domain structure [51,153]. Figure 5 shows the author's co-occurrence keyword network, represented by 142 keywords out of a total of 3174, which meet a minimum of 5 occurrences. The network is structured by 9 clusters, 142 nodes, and 1363 links and has a total strength of 3459. The nodes were represented by keywords whose size is related to the number of times they have appeared in articles: that is, the larger the size, the higher the frequency of use, while the links show the strength between the two nodes [60].

Cluster 1 (red), called 'agriculture and conservation', comprises 25 nodes with 283 occurrences. The studies found in this cluster show large clearings, such as croplands, cattle pastures, or secondary forests [30]; increased agricultural production due to the expansion of farmland and how policies should promote the use of land already cleared [120]; the evaluation of row crop expansion and crop number intensification [154]; studies on the spatial patterns of forest conversion for agricultural uses through logistic regression and classification trees [155]; satellite records for the development of maps that represent agricultural uses [156]; recent studies related to the intensification of cultivation systems, highlighting the importance of regeneration strategies [157]; the characterization of dimensions by spatiotemporal change [158]; and agricultural intensification as a development strategy [159].

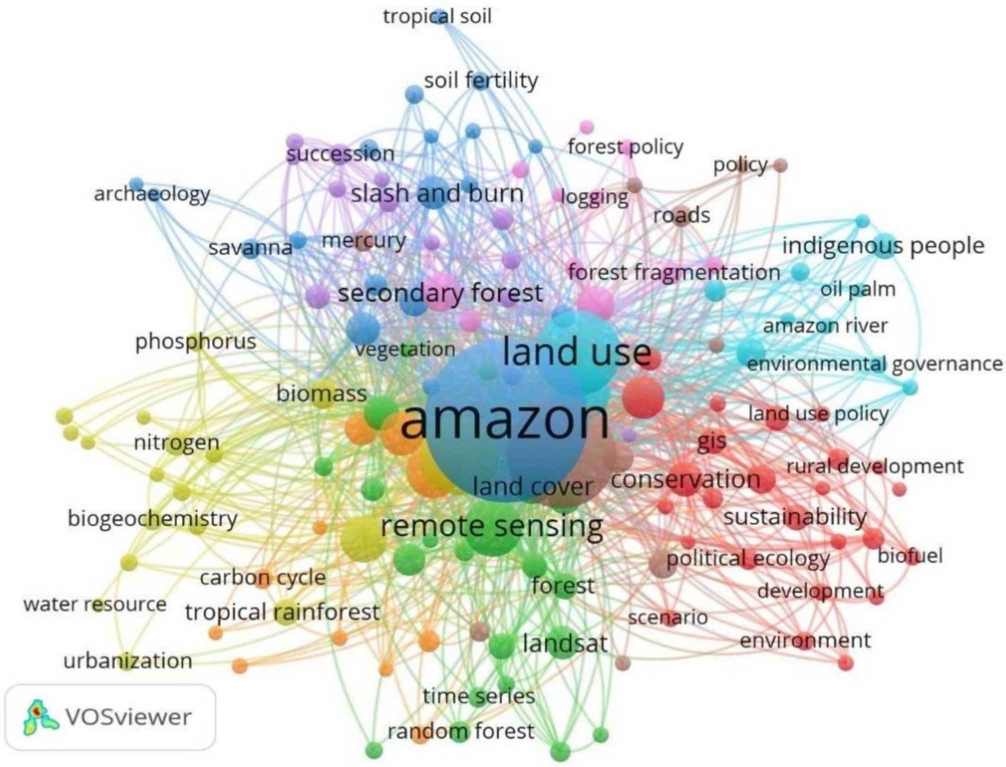

Figure 5. Co-occurrence author keyword network.

Cluster 2 (green), called 'remote sensing', comprises 21 nodes with 367 occurrences. The studies depicted in this cluster are related to the determination of the forest biomass distribution [149]; LULC classification [114]; space imaging spectroscopy [160]; plant carbon mapping [161]; and the geographic distributions of species (birds, mammals, and trees) [162]. The most recent studies are related to the mapping of forest and agricultural mosaics [163]; the use of optical satellite data and radar to the expansion of oil palm in the Peruvian Amazon [1]; and the spatial and temporal dynamics of LULC change of coverage through the use of software ENVI [164].

Cluster 3 (blue), called 'amazon', comprises 20 nodes with 812 occurrences. The research presented in this cluster deals with the determination of the spatial distribution of forest biomass employing remote sensing metrics [149]; the comparison of various forest biomass estimates based on spatial interpolations of direct measurements, relationships with climatic variables, and remote sensing [150]; the evaluation of LULC transitions, policies, and associated markets [120]; the evaluation of the effects of biophysical and anthropogenic predictors on deforestation [165]; and studies related to soil and LULC in the rates of forest successional regrowth [114]. Recent studies show how fish species respond to deforestation, while considering the different nuances of biodiversity, such as taxonomic functional assembled structures used to determine the influence in land cover [166]; methods using satellite images for the classification of LULC [167]; and the understanding of the intensification of pasture crops in the agricultural–forest frontiers through econometric analysis and remote sensing [168].

Cluster 4 (yellow), called 'land use and land cover change', comprises 18 nodes with 337 occurrences. The research pertaining to this cluster focuses on obtaining LULC change maps [169]; the simulation of the sensitivity of surface energy and water flows using the simple biosphere model [170]; and the demonstration of the incorporation of carbon and biodiversity benefits in reducing emissions from deforestation and forest degradation (REDD+) through analysis and modelling of future scenarios [171]. Other recent studies consider the estimation of impacts due to LULC changes on evapotranspiration and discharge [172]; modelling of the effects on the hydrology of a basin [7]; and models for forest management, monitoring, and evaluation [173].

Cluster 5 (purple), called 'soil', comprises 13 nodes with 109 occurrences. The research in this cluster includes a model of soil water balance [174]; changes in the apparent density of the soil and the determination of the soil's carbon origin [175]; the chemical, physical, and mineralogical properties of soils ranging from the tertiary plateau to the alluvial plain of the Amazon River [176]; changes in soil's organic carbon during intensive (annual tillage) and nonintensive (pasture, conservation tillage, and perennial crops) LULC systems [177]; and the determination of nitrogen and organic carbon reserves in soil [178]. Recent studies deal with multivariable statistical analysis in different types of LULC change in an oxisol [179]; heavy metals in soils to establish quality reference values for alluvial sedimentary soils [180]; and considerations related to phosphorus and its changes in different uses and soil textures through path analysis [181].

Cluster 6 (turquoise), called 'land use', comprises 12 nodes with 331 occurrences. The research depicted in this cluster addresses land use through the use of traditional zoning models at a household level [107]; the use of censuses and satellite registries for the development of agricultural soils maps [156]; the description of the land-use patterns of settlers in the Ecuadorian Amazon [182]; the advantages in addressing sustainability issues [183]; and the participation of families related to the various forms of land use with the change in the structure of their homes [184]. Recent studies deal with the description of the intensity of land use by monitoring management practices, such as burning pastures and treating tillage [185]; shifting cultivation as a LULC system that guarantees livelihoods by evaluating how it affects the recovery of the secondary forest [142]; and agriculture representing a dominant type of land use [186].

Cluster 7 (orange), called 'tropical forest', comprises 11 nodes with 196 occurrences. The research within this cluster shows how protected areas are a means for the conservation of tropical forests [148]; the leading to sustainable use by monitoring biological diversity and ecosystem functions through selected fragmented species used to monitor changes in the forest system [187]; how the loss of biodiversity and continuous deforestation leads to irreversible changes in forests [29]; and forest conversion, regrowth, and selective influence of carbon storage logging, nutrient dynamics, and the trace of gas flows [188]. Recent studies mention tropical forests as regulators of global climate through their interaction with hydrological and biogeochemical cycles [137], as well as the impact of selective logging on forests [189].

Cluster 8 (brown), called 'deforestation', comprises 11 nodes with 382 occurrences. The research in this cluster mentions how part of the carbon released into the atmosphere by deforestation can be determined by the amount of carbon retained in the biomass of the forests [150]; the reduction of carbon emissions derived from deforestation constitutes a strategy that seeks to mitigate climate change [8]; and the elimination of incentives that drove deforestation [108]. This cluster includes research related to the effects of LULC types in deforested areas. Recent studies mention that deforestation associated with agricultural expansion comprises a challenge for sustainable development and climate mitigation [168], in addition to evaluating the effects of deforestation on fish yield in floodplain lake systems [190].

Cluster 9 (pink), called 'forest and biodiversity', comprises 11 nodes with 142 occurrences. Research in this cluster indicates that tropical forests contain the most terrestrial species, with protected areas being the primary defense against forest loss and species extinction [191]. In addition, secondary forests can become reservoirs during periods of genetic diversity [115]. Studies of diversity patterns, deforestation, and fragmentation of ecosystems have also been presented through temporal and spatial analysis of biotic and abiotic data processed using GIS and remote sensing [133], as well as the evaluation of the impact that conversion of native ecosystems into grasslands can have on macrofauna [192]. A recent study mentions how large-scale infrastructure projects drive change in forests by threatening biodiversity and the Indigenous community [193]. On the other hand, Brazil is mentioned as a developmental model in monitoring biodiversity and reducing forests' deforestation [194].

3.2.2. Cocitation Network of Cited Authors

The cocitation analysis of cited authors is a bibliometric technique frequently used in the academic world, which evaluates a field's intellectual structure by considering the relationships between authors cited together in subsequent research, where the higher its frequency, the more similar they are [51,60]. Figure 6 illustrates this cocitation network, represented by 1659 researchers out of a total of 67,307, who have been selected by considering a minimum of 20 citations. The network comprises 7 clusters, 1659 nodes, and 633,890 links and has a total strength of 52,392.01.

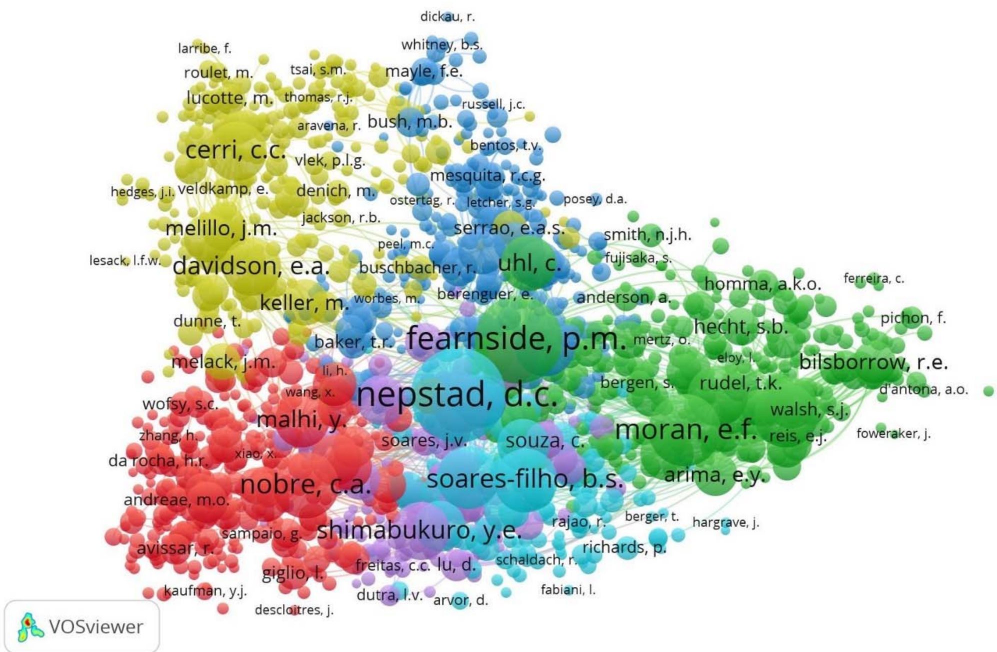

Figure 6. Co-citation network of cited authors.

Cluster 1 (red), related to 'deforestation-forest-climate', was represented by 384 authors with 21,921 citations. The studies within this cluster are related to the carbon flux from deforestation, biomass, and climate variation. The researchers Nobre C.A., Malhi Y., Coe M.T. have been highlighted.

Cluster 2 (green), called 'forest-land use-agriculture', comprises 335 authors with 25,580 citations. This research deals with converting forests to pastures, greenhouse gases from deforestation, land-use change, agricultural development, and farm management. The researchers Fearnside P.M., Moran E.F., Walker R. have been highlighted.

Cluster 3 (blue), called 'forest-fire-biodiversity', comprises 323 authors with 16,691 citations. These studies deal with deforestation rates, biomass, fire dynamics, and hunting. The researchers Laurance W.F., Cochrane M.A., and Peres C.A. have been highlighted.

Cluster 4 (yellow), called 'land use change-soil', comprises 288 authors with 16,473 citations. These studies deal with deforestation for pastures, microbial production, and nitrogen dynamics and are led by researchers Cerri C.C., Davidson E.A., and Neill C.

Cluster 5 (purple), called 'agriculture-satellite observation-carbon', comprises 189 authors with 13,759 citations. These studies deal with land use, crop expansion, fires in Amazonian forests, carbon assessment and storage, and mapping of deforestation. The researchers Shimabukuro Y.E., Asner G.P., and Houghton R.A. have been highlighted.

Cluster 6 (turquoise), called 'forest-deforestation', is made up of 139 authors with 12,351 citations. These studies are related to the soil, pastures, conservation, and landscape dynamics and are led by the researchers Nepstad D.C., Soares-Filho B.S., and Defries R.S.

Cluster 7 (orange), called 'satellite observation-land use', comprises one author with 245 citations. These studies focus on roots in the hydrological and carbon cycle and remote sensing and are represented by Lefebre P.

3.2.3. Cocitation Journal Network

The cocitation journal analysis determined the areas in which research is cited [195]. Figure 7 shows the journals, with a total of 25,097 sources, whose articles have obtained a minimum of 20 citations, represented by 234 nodes distributed in five clusters, with links of 16,691 and a total strength of 661,155.

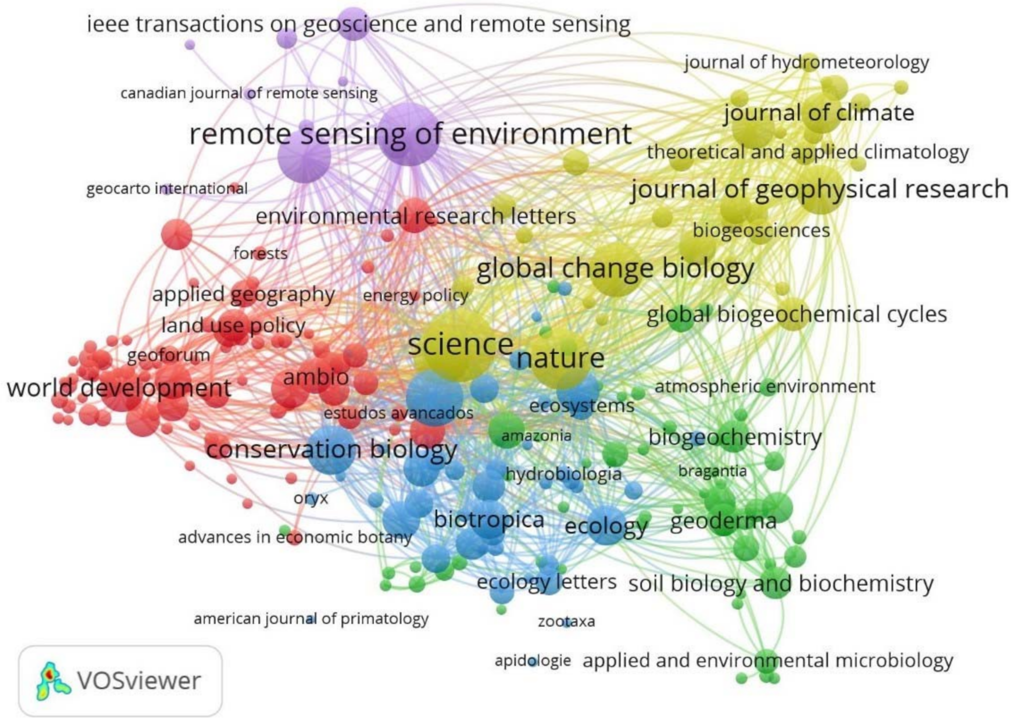

Figure 7. Journal-based co-citation clusters.

Cluster 1 (red), called 'environment', comprises 88 nodes with 9334 citations. The journals *World Development*, *Bioscience*, *Ecological Economics*, *Environmental Research Letters*, and *Agriculture, Ecosystems and Environment* stand out.

Cluster 2 (green), called 'environment-soil', was represented by 56 nodes with 5210 citations, in which the journals *Acta Amazonica*, *Geoderma*, *Soil Biology and Biochemistry*, *Biogeochemistry*, and *Oecologia* stand out.

Cluster 3 (blue), called 'ecology-biology', comprises 44 nodes with 8764 citations, in which the journals *Forest Ecology and management*, *Conservation Biology*, *Ecological Applications*, *Ecology*, and *Biotropica* stand out.

Cluster 4 (yellow), called 'nature-climate', was represented by 36 nodes with 12,357 citations, highlighting the journals *Science*, *Nature*, *Proceedings of the National Academy of Sciences*, *Global Change Biology*, and *Journal of Geophysical Research*.

Cluster 5 (purple), called 'remote sensing', was represented by 10 nodes with 3739 citations, in which the journals *Remote Sensing of Environment*, *International Journal of Remote Sensing*, *IEEE Transactions on Geoscience and Remote Sensing*, *Remote Sensing*, and *ISPRS Journal of Photogrammetry and Remote Sensing* stand out.

4. Discussion

The scientific production in this field of study began in the 20th century, with an article related to the development of crops in 1982 [92]. From this date, there was a growing interest in the scientific community, obtaining an exponential growth within 37 years, with 1590 articles, 462 journals, and an average of 36.04 citations. This increase in scientific production shows a constantly growing field of study in compliance with Price's law (see Figure 3). This production was divided into four periods: 1982–1989, with 1.19% of the contributions; 1990–1999, with 7.66%; 2000–2009, with 27.26%; and 2010–2019, which represents the period of most remarkable production, with 63.76% of the contributions (see Figure 3).

In this global context, it was identified that the most significant contribution was made by the American continent, where Brazil (1st) and the United States (2nd) stand out with 920 and 737 documents, respectively, and have a combined value of 70,891 citations (see Table 1). The European continent highlights the contributions of the United Kingdom (3rd), Germany (4th), and France (5th), with 382 documents and 13,227 citations within the top 15. These contributions can be observed graphically through the bibliographic coupling of countries, which reveals a strong cooperation link between the countries of Brazil and the United States, who maintain close cooperation with the United Kingdom (1st), Germany (2nd), France (3rd), the Netherlands (4th), and Canada (5th) (see Figure 4).

Scientific production analysis reveals that the main contributors are from the American and European continents (seven and six countries within the top 15, respectively, see Table 1). However, the leading researchers are not just from the Amazon region, such as Brazil, but also from the United States, the United Kingdom, and Sweden (see Table 3). On the other hand, the principal investigators' affiliations of the most cited articles correspond to institutions in Canada, the United States, and the United Kingdom.

Based on the analysis of the intellectual structure, we first considered the co-occurrence author keyword (see Figure 5), where the most mentioned topics in this field of study correspond to 'Amazon' (610 occurrences), 'deforestation' (278 occurrences), 'land use' (167 occurrences), 'land use change' (144 occurrences), and 'remote sensing' (81 occurrences). The word 'Amazon' (Cluster 3) has strong links to deforestation, 158 link strength (Cluster 8); land use, 97 link strength (Cluster 6); land-use change, 76 link strength (Cluster 4); and remote sensing, 42 link strength (Cluster 2).

Regarding Cluster 8, the Brazilian Amazon stands out for its high deforestation rate due to population density, roads, and dry weather seasons. Deforestation processes lead to carbon release into the atmosphere [165]. In addition, the expansion of crops, leads to the challenge of finding appropriate practices in using the land, so as to reduce the soil's degradation and contamination [129]. On the other hand, Cluster 6 shows that rural progress gives a boost to agricultural development, which was characterized by deforestation and a decrease in biodiversity in the Amazon region [29], with the increase of land cultivation and grasslands [156]. Given this, the conservation of primary forests by establishing protected areas constitutes the leading way to preserve biodiversity, especially if they are inaccessible areas with laws protecting them [191]. Based on Cluster 4, the change in land use that has occurred for cattle pastures has presented negative consequences in the context of biodiversity, due to the decline in the number of species of flora and fauna and homogeneity in the microbial community [25]. The change from forests to croplands was promoted due to the international market [30]. Additionally, fires are frequent in deforested areas due to forest material piling [2]. On the other hand, Cluster 2 shows that the use of remote sensing has made it possible to classify land cover [114], model the geographical distribution of species [162], create maps of land use [28], and map the burned areas [196,197]. In addition to the use of optical satellite images, synthetic aperture radar images have been used for mapping coverage and land use due to the advantage that radar systems have of not depending on the climatic conditions [163,198].

Second, we considered the author's cocitation network (see Figure 6), which shows the main lines of research, where Cluster 5 ('agriculture-satellite observation-carbon') and Cluster 6 ('forest-deforestation') are intertwined, showing studies about droughts through the use of spatial images [160] and the characterization of deforested areas as crops or pastures [30]. Cluster 1 ('deforestation-forest-climate') has intertwined with Cluster 6, showing studies about forests affected by fires [121], studies of surface energy, and studies of water flows due to the change in land cover [170].

5. Conclusions

This study comprises a bibliometric analysis of land cover and land use in the Amazon Region. The intellectual structure of 1590 articles indexed in the Scopus database from 1982 to 2019 was analyzed. These types of documents went through peer review as part of a rigorous publication process. The first record was titled 'Amazon Basin soils: management for continuous crop production' and was published by Sanchez et al. [92] in the journal *Science*. The most significant scientific production took place during the 2010–2019 period, with 1014 publications, which represents 63.76% of the total. The most cited article is 'Atmospheric science: The importance of land-cover change in simulating future climates' by Feddema et al. [6], published in the journal *Science*, with 660 citations.

In this study, scientific production focuses on the American continent, with Brazil and the United States as the largest producers, with 1657 articles and 70,891 citations. Regarding the latter, the United States stands out with 37,429 citations and 737 documents, but based on the number of documents, Brazil surpasses it with 920 articles and 33,462 citations.

The intellectual structure of land use and cover in the Amazon was also considered. First, the author's keyword co-occurrence network was represented by 9 clusters with 142 nodes, where the term Amazon has 610 occurrences and is related to 138 terms. The clusters were named 'Agriculture and conservation', 'Remote sensing', 'Amazon', 'Land use and land cover change', 'Soil', 'Land use', 'Tropical forest', 'Deforestation', and 'Forest and biodiversity'. The area of greatest relevance comprised Cluster 3 ('Amazon') with 812 occurrences, highlighting research related to studies of forest biomass, evaluations of land use, the effects of biophysical and anthropogenic predictors, and the use of satellite images for the classification of land cover and use. Cluster 8 followed ('deforestation') with a total of 382 occurrences, whose studies are linked to the carbon of the forest biomass, cover and land use of deforested areas, and the effects that deforestation has on fishing performance. Cluster 2 ('remote sensing') presents a total of 367 occurrences, highlighting research related to geographic distribution models of species and forest and agricultural mapping. Cluster 4 ('land use and land cover change') presents 337 occurrences, with studies related to the simulation of surface energy and water flows through a simple biosphere model and the analysis of the rates and patterns of land cover change. Cluster 6 ('land use') presents a total of 331 occurrences, with investigations related to land-use zoning models and the elaboration of maps of agricultural land uses.

Second, the author cocitation network comprises seven clusters with 1659 nodes, which constitute the topics related to the study topic: 'Deforestation-forest-climate', 'Forest-land use-agriculture', 'Forest-fire-biodiversity', 'Land use change-soil', 'Agriculture-satellite observation-carbon', 'Forest-deforestation', and 'Satellite observation-land use'. The most relevant researchers are Nepstad D.C., Fearnside P.M., Moran E.F., Nobre C.A., and Soares-Filho, B.S., with affiliations to the Earth Innovation Institution (United States), Instituto Nacional de Pesquisas Da Amazonia (Brazil), Michigan State University (United States), Universidade de Sao Paulo (Brazil), and Universidade Federal de Minas Gerais (Brazil), respectively.

Third, the network of cocitation of scientific sources was represented by five clusters, which show the fields of knowledge in which the field of study has developed: 'Environment', 'Environment-soil', 'Ecology-biology', 'Nature-climate', and 'Remote sensing', where the journals *Science* (2419 citations), *Remote Sensing of Environment* (1722 citations), *Nature* (1542 citations), *Forest Ecology and Management* (1356 citations), and *Proceedings of the National Academy of Sciences* (1295 citations) stand out for their high numbers of citations.

Furthermore, it is necessary to consider that this study has some limitations: (i) despite the use of the Scopus database, other scientific databases, such as Web of Science or Dimensions, were not included; (ii) other types of documents, such as conferences, books, and book chapters were not considered in this study; (iii) the contributions of the year 2020 were also not considered due to possible updates in the Scopus database. We consider that subsequent studies could review these limitations in order to deepen this field of research.

It is important to have a background on what topics are being research regarding the Amazon region, given its important contribution to the stabilization of the global climate. The studies presented in this article can indicate the themes that require deeper analysis in order to increase contributions to the reduction in deforestation rates and the loss of biodiversity. It is also important to consider the creation of public policies that can improve the quality and sustainability of the livelihoods of the Amazonian population, among others.

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