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Review

GIS Spatial Analysis Modeling for Land Use Change. A Bibliometric Analysis of the Intellectual Base and Trends

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Abstract: The paper aimed to express the cognitive and intellectual structure of research executed in the field of GIS-based land use change modeling. An exploration of the Web of Science database showed that research in GIS spatial analysis modeling for land use change began in the early 1990s and has continued since then, with a substantial growth in the 21st century. By science mapping methods, particularly co-coupling, co-citation, and citation, as well as bibliometric measures, like impact indices, this study distinguishes the most eminent authors, institutions, countries, and journals in GIS-based land use change modeling. The results showed that GIS-based analysis of land use change modeling is a multi- and interdisciplinary research topic, as reflected in the diversity of WoS research categories, the most productive journals, and the topics analyzed. The highest impact on the world sciences in the field have can be attributed to European Universities, particularly from The Netherlands, Belgium, Switzerland, and Great Britain. However, China and the United States published the highest number of research papers.

Keywords: science mapping; bibliometrics; systematic literature review; land use change; GIS; spatial analysis; land use change drivers; land use change consequences

1. Introduction

Land use change is one of the determinants that shape the Earth's surface, and, since the twentieth century has caused a profound ecological impact, as itemized by Chapin III et al. [1], greater than any other global change. In the mid of 90s. Vitousek [2] listed the ongoing land use/land cover changes as one of the three best-documented global changes, beyond concentrations of carbon dioxide in the atmosphere and modifications in the biogeochemistry of the global nitrogen cycle. Lambin et al. [3–5] focused on deforestation and agriculture intensification as the largest land use changes during recent decades. Seto et al. [6], however, noted that urbanization is one of the most irreversible human impacts on the biosphere, which leads to a loss of agricultural land, threatens biodiversity, and ultimately affects the local climate.

The various land use change (referred to hereafter as LUC) models, that have been developed over the past three decades, enable the assessment and simulation of the future role of land use/land cover change in the functioning of the ecosystem, as well as meeting land management needs at every level, from local to global. GIS-based land use change models represent, albeit only partially, the complexity of land use systems and land use science. Spatially explicit LUC models as noted by Lambin et al. [3,7,8] are important, integrated, and multi-scale tools for developing alternative scenarios of future land use, executing experiments that test and enrich our knowledge of crucial processes, and for portraying the latter in quantitative and qualitative manners. Moreover, these models offer the possibility to assess land use or landscape patterns for their sensitivity to change based on geospatial environmental and statistical socio-economic variables.

Many meta-studies, bibliometric analyses, and review papers dealing with land use change models, and some of them also raise issues related to land use modeling using GIS methods and tools. Meta-studies, that through a systematic literature review, synthesize published case-studies, present, e.g., long-term urbanization trends across the globe [6,9], deforestation and its drivers [5] with special attention to tropical forests [10]; agricultural land desertification [8,11] and intensification [12], impact of agricultural land change on landscape and urban services [13], or wetland conversion [14]. However, as noted by van Vliet et al. [15], the meta-studies of land use/land cover change processes and driving forces are still limited. LUC modeling is increasingly important with a wide range of applications that utilize numerous modeling and computational approaches, especially those spatially embedded. Research studies categorize LUC models based on different criteria and aims. Based on in-depth literature review, Mas et al. [16] distinguished the following dichotomous LUC model types: static or dynamic, spatial and nonspatial, inductive or deductive, and pattern- or agent-based. Michetti and Zampieri [17] distinguished stand-alone models, further divided into geographical and economic models, and related or integrated models, which in turn provide a framework for the interaction of both the geographical and economic models. The authors emphasize some strength and limitations of the modeling category and conclude that collaboration between scientists is required to achieve maturity in LUC modeling in a quantitative and qualitative manner, as well as climate-human-earth interactions. Many studies emphasize that important step in model building is the selection of appropriate methods and techniques [4,6,7,17–20]. Nevertheless, Dang and Kawasaki [18] concluded that, while current integrated approaches have enormous potential, more work is needed to improve the modeling of land use dynamics.

This study aimed to provide a word-wide broad picture of spatially explicit land use change (interchangeably referred to as GIS-based) models and to assess current progress in this field based on a systematic literature review and bibliometric analysis. In particular, it focuses on (1) the most influential authors, journals, countries, and organization, (2) research publications that provide the intellectual bases for land use change models, and (3) hot spot and emerging research trends in the field. Furthermore, this study raises the important issue of the definition, understanding, and application in scientific literature of the two key concepts, namely land cover and land use. Contrary to, so far, published meta-studies on land use change models, this paper contributes to the discourse on publications based on Geoscience theory and methods, as well as land use change application directly related to the Earth's surface. The paper is expected to achieve two main goals. Firstly, it is supposed to assist academics to get a quick and insightful overview of the research on land use change modeling based on spatial and GIS analyses. Secondly, thanks to a comprehensive review of scientific publications, especially a summary and analysis of existing research, research trends and hot spots, as well as still unresolved problems in spatially explicit land use modeling, will help scientists find a gap and undertake relevant research in this field. The remainder of the paper is structured as follows. The next section, Materials and Methods, describes the data used and the methods of investigation. Thereafter the results are presented and discussed, and, finally, some concluding remarks summarize the conducted study.

2. Materials and Methods

2.1. Research Methodology

The research follows the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) Statements methodology, structured in five steps [21]: (1) data search strategy, (2) data collection, (3) data screening and data cleaning, (4) quantitative and qualitative analysis of the publication output, and (5) interpretation (see Figure 1). A bibliometric set of similarity measures, based on plot graphs constructed between the analyzed items (documents, authors, journals, countries, or organizations), was used to present major achievements in this field (i.e., GIS and spatial analysis models for land use change), as well as identify new avenues for future research. Citations and

co-occurrence networks were investigated in detail. As stated by Garfield in the late 1970s [22], citations (i.e., direct citation, co-citation, and bibliographic coupling) are the acknowledgements that publications receive from one another. Citations give the credit to previous research, by referring to the pioneers the intellectual basis in the field, and, on the other hand, by citing the latest works, they reveal the emerging trends in research. Highly cited papers are usually seen as hot spots. Co-citation, by emphasizing the frequency with which two papers are cited together by other research documents, is a good index for the new scientific topics' emergence. The co-citation strength between two documents shows their semantic relatedness [23]. In general, bibliographic coupling is mainly retrospective, whereas co-citation is essentially a forward-looking perspective.

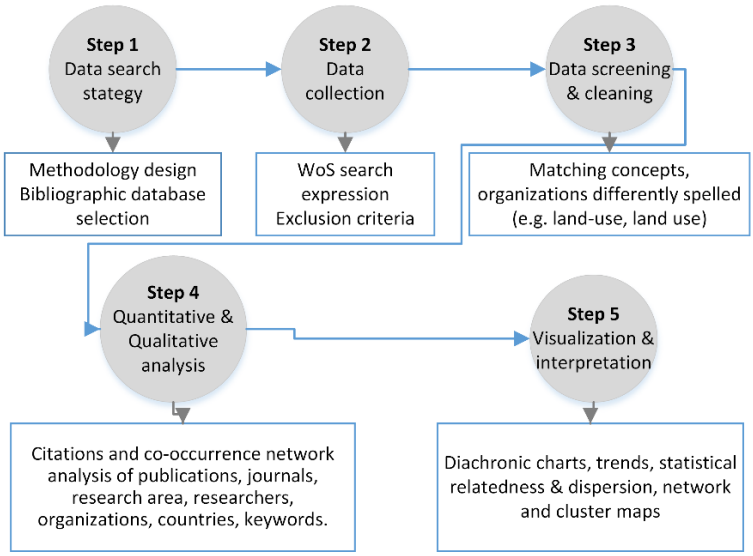


Figure 1. Bibliometric and systematic literature review workflow.

Co-occurrence networks portray relations between authors, organizations, countries, keywords, or other entities represented within the analyzed set of publications and are seen as a carrier of meaning in various research fields [24]. Co-occurrence networks are generated by connecting pairs of items using a set of criteria-defining co-occurrence, whereas the graphic representation of co-occurrence is visualized based on the relationships between analyzed items (authors, concepts, organizations, etc.). The co-occurrence is expressed by the Links (L), i.e., the number of links of an item (author, publication, organization, or country) with other items, and Total link strength (TLS), which indicates the total strength of the links of an item with other items [25].

Summarized and synthesized information from prior expertise and studies on the LUC spatially explicit models provides insights into three research issues:

1. The portrayal of the evolution, including the dynamics and trends, in scientific publications over the last three decades.
2. Analysis of the collaboration activities of authors, organizations, and countries.
3. Presentation of the intellectual base for GIS-based land use change models, emerging problems, and research challenges.

2.2. Data Acquisition and Workflow

The Web of Science (WoS) Core Collection was chosen as the main data source due to its multidisciplinarity and guarantee of high-quality indexed publications [23]. The search was performed through the general search interface, looking for such terms as "land use" "land cover" "change", "spatial analysis", "GIS analysis", "spatial model", and "GIS model" combined using the Boolean operations OR and AND, as well as NEAR/x. The NEAR/x operator searches for records containing

keywords separated by the x number of other words, e.g., "land use NEAR change" searches for publications where the words 'land use' and 'change' occur right after each other, i.e., they form a logical phrase. The period of conducted analyses was limited to begin in 1960. Only articles, book chapters, and conference papers in English were considered (Table 1). The WoS website search took place on 11 October 2020.

Table 1. Data collection criteria.

Criteria	Details
Terms searched	TOPIC: (land use NEAR change Near spatial NEAR analysis) OR TOPIC: (land use NEAR change Near model NEAR spatial NEAR analysis) OR TOPIC: (land use NEAR change Near model GIS NEAR spatial NEAR analysis) OR TOPIC: (land cover NEAR change Near spatial NEAR analysis) OR TOPIC: (land cover NEAR change Near spatial NEAR analysis)
Publication period	1960–2020 (October)
Language	English
Document type	articles, book chapters, conference proceedings

An initial search using the aforementioned keywords revealed 1535 research publications; however, following the exclusion criteria, i.e., Early Access, editorial and books (21 documents), and non-English language of publication (32 documents), the detailed analyses comprised of 1482 scientific publications. The analysis methods, along with the objectives, indicators, and tools used, are summarized in Table 2, while the workflow is presented in Figure 1. The bibliometric network analysis of documents, authors, organizations, countries, and the co-occurrence analysis of keywords was conducted using VOSviewer [25], InCite [26], and MS Excel.

Table 2. Research objectives, methods, bibliometric indicators, and software.

Objectives	Method	Indicator	Software
Dynamics and trends in research publication	Citation analysis	Number of publications and citations per year, most productive authors, and journals, statistical indicators (i.e., std. dev., relative standard deviation (RSD), variance-to-mean ratio (VMR), R-squared)	InCite, MS Excel
Collaboration between authors, organizations, and countries	Co-occurrence network	Links (L), total link strength (TLS), number of publications	VOSviewer
Intellectual base, research problems and challenges	Citation, co-citation, bibliographic coupling	Links (L), total link strength (TLS), number of publications/citations	VOSviewer InCite,

The fractional counting method was used because it equally weights analyzed items (i.e., authors, documents, organizations, or countries) regardless of the number of authors, citations, or references of a publication [27].

3. Results

3.1. Scientific Productivity in the Field of GIS Spatial Analysis Modeling for Land Use Change

The total number of publications in 1992–2020 (11 October) on GIS spatial analysis modeling for land use change extended 1482. Until 2000, only a few research papers were published annually in the scientific journals indexed in WoS. Thereafter, the number of publications grew slowly, with a slight decline in 2006 and 2011, marked in red in Figure 2. The annual increase in the global number

of publications exhibited the second-degree polynomial (R square = 0.989). Most of the analyzed documents were articles, constituting 80.6%, 17.8% were conference proceedings, and the remaining 1.6% book chapter. On thousand four hundred and seventy-seven publications were cited 37,254 times, and only two documents were never quoted. The average number of citations per document was 25.14, with the number of citations fluctuating widely, from 1443 to 0, with the variance-to-mean ratio (VMR) of 3.29. The percentage of articles cited at least 100 times is almost 5 (70 documents). As many as 27 scientific papers were cited over 200 times.

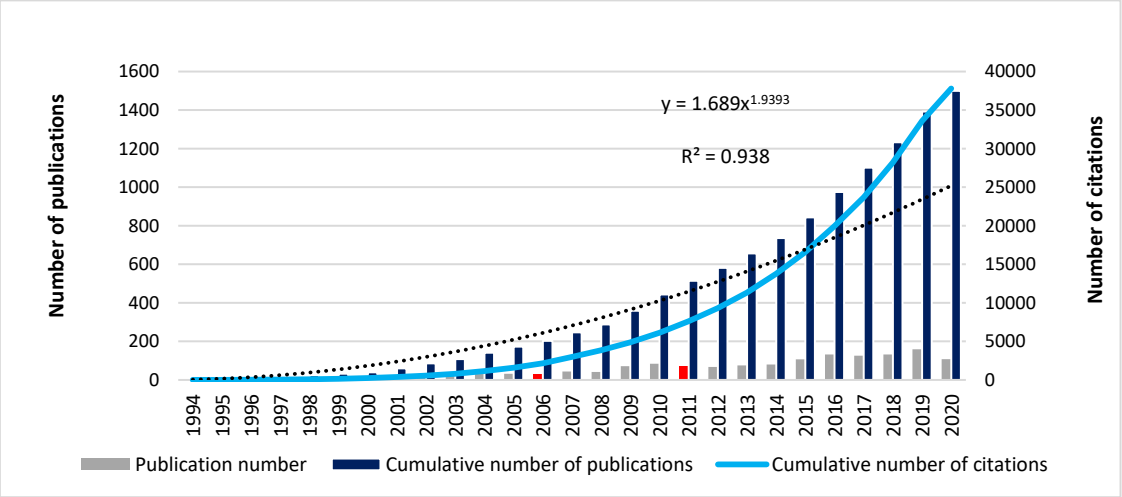


Figure 2. Diachronic productivity of the research.

Out of 5176 authors, as many as 4536 (87.6%) published just one scientific paper on spatial modeling of land use changes using GIscience and GIS tools. Five or more articles were written by 31 scientists (0.6%), including Peter H. Verburg from Virje University (The Netherlands), the author of 20 articles on the analyzed research topics (Table 3). Moreover, Verburg P.H. received the highest h-index, equaling 79. Apart from Verburg, authors who have a very large influence on the development of research on GIS-based spatial analysis of land use change modeling, measured by h-index, are: Govers G. from Katholieke Universiteit Leuven, Belgium (h = 75), and Lambin E. F. from Stanford University, USA, both conducting studies in the field of environmental science, ecology, and geography. However, research interests concerning GIS-based spatial modeling of land use changes constitute only a small fraction of the total number of publications, from 1.99% to 8.57%.

Table 3. The 10 most prominent authors ordered by the number of publications in the field.

Author	Institution, Country	TP [1]	%ISI [2]	TP ISI [3]	h-Index [4] (R)	Main Research Topics Using CLC Data	Highly Cited Paper in the Field; TC [5]
Verburg, Peter H.	Vrije Universiteit Amsterdam, The Netherlands	20	6.13%	326	79 (1)	Environmental sciences, ecology, geography	[28], 780
Veldkamp, Tom, A.	University of Twente, The Netherlands	11	6.71%	164	48 (4)	Environmental sciences, ecology, geography	[28] 780
Zhang, Yan	Beijing Normal University, China	12	5.48%	219	33 (7)	Environmental sciences, engineering environmental	[29], 74

Table 3. *Cont.*

Author	Institution, Country	TP [1]	%ISI [2]	TP ISI [3]	h-Index [4] (R)	Main Research Topics Using CLC Data	Highly Cited Paper in the Field; TC [5]
Liu, Yaolin	Wuhan University, China	8	8.51%	94	19 (9)	Environmental sciences, remote sensing	[30], 67
Lambin, Eric F.	Stanford University, USA	7	3.66%	191	64 (3)	Environmental studies, ecology, remote sensing, geography	[31], 315
Poesen, Jean	Katholieke Universiteit Leuven, Belgium	7	3.59%	195	37 (5)	Geosciences multidisciplinary, geography	[32], 171
Deng, Xiangzheng	Chinese Academy of Sciences, China	7	3.70%	189	31 (7)	Environmental sciences, meteorology	[33], 57
Salvati, Luca	Italian Council of Agricultural Research and Economics, Italy	6	1.99	301	36 (6)	Environmental sciences, geography, green sustainable science technology	[34], 133
Govers, Gerard	Katholieke Universiteit Leuven, Belgium	6	2.01%	299	75 (2)	Geosciences multidisciplinary, soil, geography	[35], 183
Zhanqi, Wang	China University of Geosciences, Wuhan, China	6	2.4%	125	7 (10)	Environmental studies, green sustainable science technology	[36], 19

[1] TP: total publication in the field, [2] % ISI: % of all ISI indexed publication; [3] TP ISI: total number of ISI publication; [4] h-index: Hirsch index; [5] TC: total number of citations of GIS spatial analysis modeling for land use change related papers; R: rank.

The most cited article was that by de Groot et al. [37], entitled "Challenges in integrating the concept of ecosystem services and values in planning, landscape management and decision making" and published by the Springer Ecological complexity in 2010. The paper was marked by WOS as a highly cited hot spot, receiving 1443 citations. The article by Verburg et al. [28] on the framework and applications of the CLUE-S (Conversion of Land Use and its Effects at Small at small regional extent) model came second, receiving 780 citations over an 18-year period (see Table 4).

Table 4. Highly cited papers (more than 200 citations) referred to GIS spatial analysis modeling for land use change.

Authors	Publication Title	Journal Name; JRC Journal Category; IF (2019)	Pub. Date	Total Citati-ons	Av. Cit./Year
De Groot, R. S.; Alkemade, R.; Braat, L.; Hein, L.; Willemen, L.	Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making [37]	*Ecological Complexity*; Ecology; 1.571	Sep. 2010	1443	130.91
Verburg, P.H.; Soepboer, W.; Veldkamp, A.; et al.	Modeling the spatial dynamics of regional land use: The CLUE-S model [28]	*Environmental Management*; Environmental sciences; 2.561	Sep. 2002	780	43.33
McGuire, A.D.; Sitch, S.; Clein, J.S.; et al.	Carbon balance of the terrestrial biosphere in the twentieth century: Analyses of CO2, climate and land use effects with four process-based ecosystem models [38]	*Global Biogeochemical Cycles*; Environmental sciences; 5.74	Mar. 2001	545	28.68
Luck, M.; Wu, J.G.	A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan region, Arizona, USA [39]	*Landscape Ecology*; Ecology, geography physical; 4.354	2002	509	26.79
Metternicht, G.I.; Zinck, J.A.	Remote sensing of soil salinity: potentials and constraints [40]	*Remote Sensing of Environment*; Environmental sciences, Imaging science; 9.626	April 2003	491	28.78

Table 4. *Cont.*

Authors	Publication Title	Journal Name; JRC Journal Category; IF (2019)	Pub. Date	Total Citati-ons	Av. Cit./Year
Weng, Q.H.	Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modeling [41]	*Journal of Environmental Management*; Environmental sciences; 5.708	Mar. 2002	480	26.67
Zorner, R.J.; Trabucco, A.; Bossio, D.A.; Verchot, L.V.	Climate change mitigation: A spatial analysis of global land suitability for clean development mechanism afforestation and reforestation [42]	*Agriculture Ecosystems & Environment*; Agriculture, Ecology, Environmental Sciences; 4.241	Jun. 2008	469	39.08
Seto, K.C.; Fragkias, M.	Quantifying spatiotemporal patterns of urban land-use change in four cities of China with time series landscape metrics [6]	*Landscape Ecology*; Ecology, geography physical; 4.354	Nov. 2005	411	27.4
Stow, D.A.; Hope, A.; McGuire, D.; et al.	Remote sensing of vegetation and land-cover change in Arctic Tundra Ecosystems [43]	*Remote Sensing of Environment*; Environmental sciences, Imaging science; 9.626	Feb. 2004	406	25.38
Serra, P.; Pons, X.; Sauri, D.	Land-cover and land-use change in a Mediterranean landscape: A spatial analysis of driving forces integrating biophysical and human factors [34]	*Applied Geography*; Geography; 4.241	July 2008	337	28.08

Word-wide research on GIS spatial analysis modeling for land use change covered 105 the WoS research categories, which is about 30.1% of all research areas. The number of publications assigned to a WoS category ranged from 1 to 449, with an average of 29.97, standard deviation—66.87. Eighty percent of all publications in this field came from 15 WoS research areas. The five top research categories (with more than 200 papers) were accounted to: Environmental Sciences (494 research articles), Remote Sensing (223), Ecology (220 articles), Environmental Studies (208 papers), and Geography and Geosciences Multidisciplinary (208 articles).

The diversity of the WoS research categories is reflected in the variety of journals in which the analyzed articles were published. Authors' research on land use change based on GIS and spatial modeling has been published in 389 scientific journals. The average number of articles in a journal did not exceed 3, at just 2.86, and the highest reaching 38. A high dispersion of the number of articles is observed, as shown by relative standard deviation (RSD) = 0.20, std. dev = 4.47, and VMR = 6.91. Most journals, as many as 73 (19%), published only one article on the topic in question, whereas three journals, namely *Sustainability*, *Science of the Total Environment*, and *Landscape Ecology*, each issued more than 30 articles on the matter. The most prominent journals that issued research on GIS spatial analysis modeling for land use change were: *Landscape and Urban Planning*, as well as *Science of the Total Environment*, with a 5-year impact factor of 7.185, and 6.419, respectively (Table 5). However, *Agriculture Ecosystems & Environment* provided the most highly cited articles, with cited references per publication (CPP) equal to 96.2. Articles published in top journals were cited an average of 46.1 times, which significantly influenced further research.

Table 5. The top 10 productive journals.

Journal	TP [1]	IF [2]	IF 5-Year (R) [3]	TC [4]	CPP [5]
Sustainability	38	2.576	2.798 (9)	229	6.0
Science of the Total Environment	36	6.551	6.419 (2)	712	19.8
Landscape Ecology	31	3.385	4.354 (6)	2409	77.7
Ecological Indicators	28	4.229	4.968 (4)	745	26.6
Land Use Policy	27	3.682	4.151 (8)	660	24.4
Agriculture Ecosystems & Environment	25	4.241	4.825 (5)	2405	96.2
Applied GEOGRAPHY	23	3.508	4.241 (7)	1163	50.6
Remote SENSING	22	5.509	5.001 (3)	364	16.5
Landscape and Urban Planning	20	5.441	7.185 (1)	1396	69.8
International Journal of Remote Sensing	20	1.903	2.273 (10)	1484	74.2

[1] TP: total number of publications on the analyzed topic, [2] IF: 2019 ISI impact factor; [3] R: rank; [4] TC: total citations, [5] CPP: cited references per publication.

3.2. Collaboration and Geographic Distribution

The authors' cooperation in years 1992–2020 in the study of changes in spatial land use was generally small. The analysis revealed that, for 18.75% of authors, the total link strength (TLS) value did not exceed 1 (see Figure 3, gray clusters); for 399 authors (7.3%), it was greater than 10; and, for seven authors, TLS was greater than 50, which indicated strong co-operation of the authors. The graphical representation of the network of scholars' co-authorship employs different sized interconnected circles to define the relationships between scholars/authors. The circle size shows the authors' co-operations expressed as the number of links between other researchers, whereas the width of lines portrayals the measured co-operation strength. The distance between the authors indicates the relatedness of collaboration. The most collaborative authors are Li Xia (TLS = 79), Liu Yaolin (TLS = 79), and Wang J. (TLS = 65). Verburg P.H., the highly cited scientist leading in the yellow cluster, has a TLS equal to 26. The remaining prominent authors in the field, as indicated in Table 3, were characterized by TSL varied from 10 (Velcamp A.) to 33 (Zhang Yan).

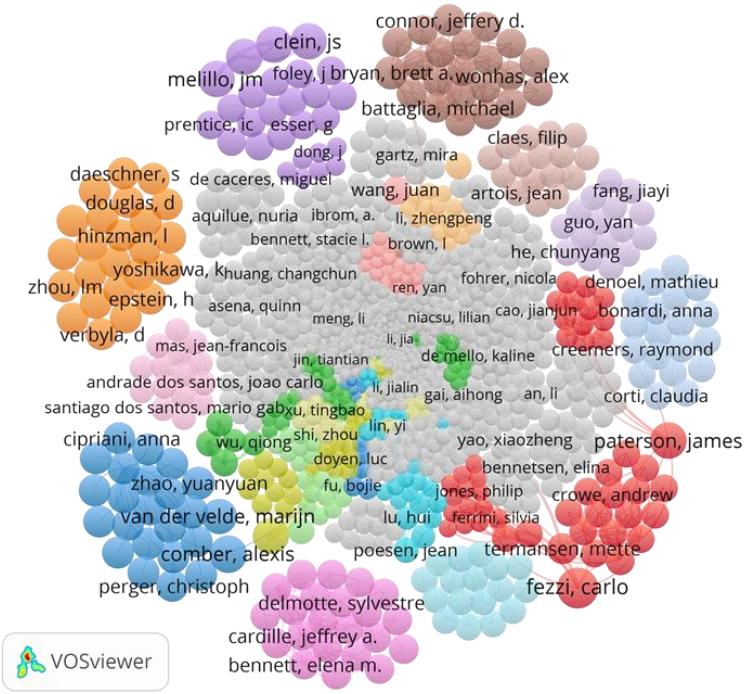
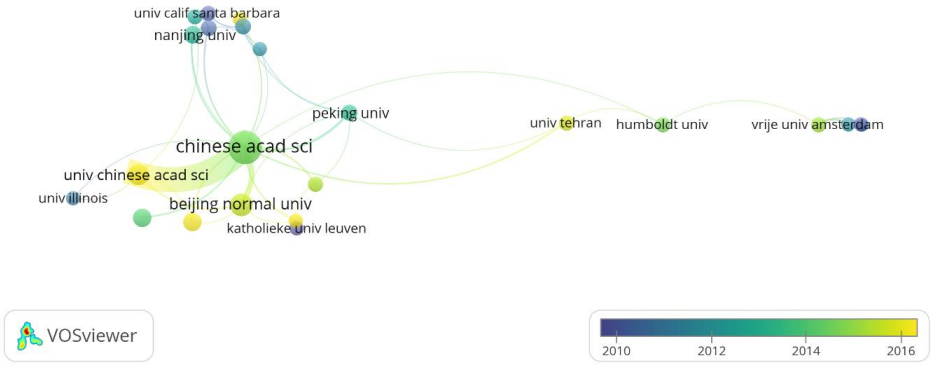


Figure 3. Network of scholars' co-authorship, lin/log modularity clustering (147 clusters).

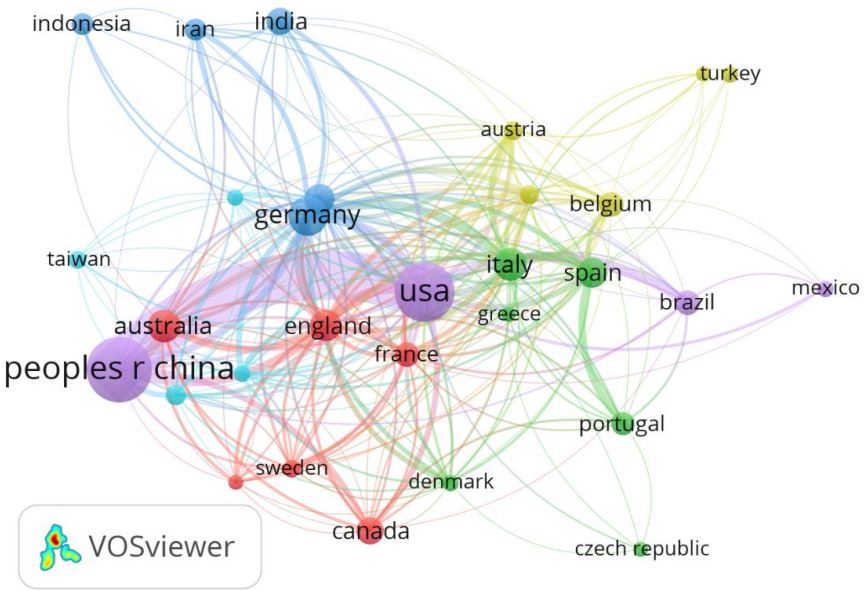
It can be noticed that co-operation of authors is very diversified and, generally, on a national level, as it is seen on Figure 3, the grey clusters. The largest, red cluster is composed of 47 authors, mainly from European universities (e.g., Great Britain, Germany, Italy, Finland). Nevertheless, the large number of authors in the red cluster does not indicate close cooperation in spatial analysis of land use change studies. Figure 3 clearly shows that scientists grouped in this cluster form three subgroups, rather weakly related to each other, which is indicated by the large distance between the authors. This can be explained by the fact that the spatial analysis of land use changes is a marginal part in their studies, as an element supporting their main research lines. The environment and ecological economics are the main research areas of the subgroups led by Ian J. Bateman of the University of Exeter Business (UK) and Fezzi Carlo of the University of Trent (Italy), while global climate change, global ecology and biogeography dominate in research conducted by scientists from a third (the upper one—Figure 3) subgroup led by Carl Beierkuhnlein from the University of Bayreuth (Germany). The green cluster of Chinese scientists consists of four subgroups, of which only one (located in the lower left corner near the blue cluster) includes widely interrelated authors of 3–5 articles (TSL = 19 on average). The yellow cluster headed by PH Verburg and A. Veldcamp comprises 30 authors,

among them prominent researches in the field as Liu, Yaolin, and de Groot, R. S. The dark pink cluster (24 people), located in the middle lower part of the network, represents a group of highly related cooperation, where both TL and TSL have a value of 21. Ecology and ecosystem services are the main scientific fields in this group of researchers from MacGill University, Montreal (Canada), and academics from France (e.g., Montpellier, Grenoble).

The supremacy of Chinese research organizations in the number of publications had started in 2014 (Figure 4a). The national character of this cooperation is underlined by the large distance between the Chinese organizations (Figure 4a, on the left), University of Teheran, European universities (e.g., Humboldt University, Virije University, Amsterdam University), or American (e.g., University of California, Univ. of Santa Barbara) grouped upper clusters. In terms of citations, however, the leader was Wageningen University & Research (The Netherlands), with 12 publications cited 2878 times, followed by the University of Wisconsin, USA (five articles cited 809 times), and the Belgian Catholic University of Leuven (eleven research papers cited 641 times). The most collaborating research institution, both nationally and internationally, was the Chinese Academy of Sciences, which conducted research with all major Chinese universities, five state USA universities, Tehran University, and Humboldt University. The TSL of the Chinese Academy of Sciences amounts to 63 and has the highest value, as, for other scientific organizations, TSL ranges from 2 to 12.



(**a**)



(**b**)

Figure 4. Cooperation network of (**a**): organizations with 10 documents threshold; (**b**): countries with 15 documents threshold.

Eight out of the 98 investigated countries did not conduct research in the analyzed field of an international nature (five from Eastern Europe and three from Asia). The biggest cluster (see the red cluster on Figure 4b) is led by England (L = 26, TLS = 132) and included 26 countries from three continents (Europe (14), Asia (6), America (4), and New Zealand and Australia). The United States, with a links number (L) of 27, received the highest total link strength, TLS = 227, demonstrating extensive international cooperation with China, Europe (England, Germany, France, Italy, and Spain particularly), Brazil, Canada, Mexico, and some Asian countries, like Indonesia and Taiwan. The second strongly cooperated country was China (TLS = 168), which conducted research on GIS-based land use change analysis together with the USA, European countries, Canada, Brazil, India, and Australia and New Zealand. The oldest, since 2012, and the strongest cooperation for China has been with the USA, and then, since 2014, also with England and Germany. Germany cooperates with other European countries—Germany, Italy, and The Netherlands have the broadest international cooperation with many countries from all continents, with 27, 26, and 25, correspondingly. Nevertheless, when analyzing the scientific importance of the publications, measured by cited references per publication (CPP), Europe is definitely the leader, in particular The Netherlands, Belgium, and Switzerland, for which the CPP ratio amounted to 78, 63, and 60, respectively. China and the USA, leading in the number of published articles (434 and 359, correspondingly), ranked 18th and 8th with CPP indices of 13.44 and 35.29, respectively, which shows that they have had a low impact on world science in the GIS-based land use change modeling so far.

3.3. Main Research Areas, Intellectual Structure, and Emerging Trends

The land use science mapping, based on the co-citation and bibliographic coupling of documents, as well as keywords analysis (see Figure 5), has manifested the following research areas of interest:

1. land use change documentation, especially the analysis of land flows and trajectories, i.e., urban growth, deforestation, and agricultural intensification, as well as the causes of land use change.
2. Land use changes in relation to environmental changes, including climate, soil, water, and ecosystem services.
3. Prediction of future land use based on geographical and socio-economic factors.

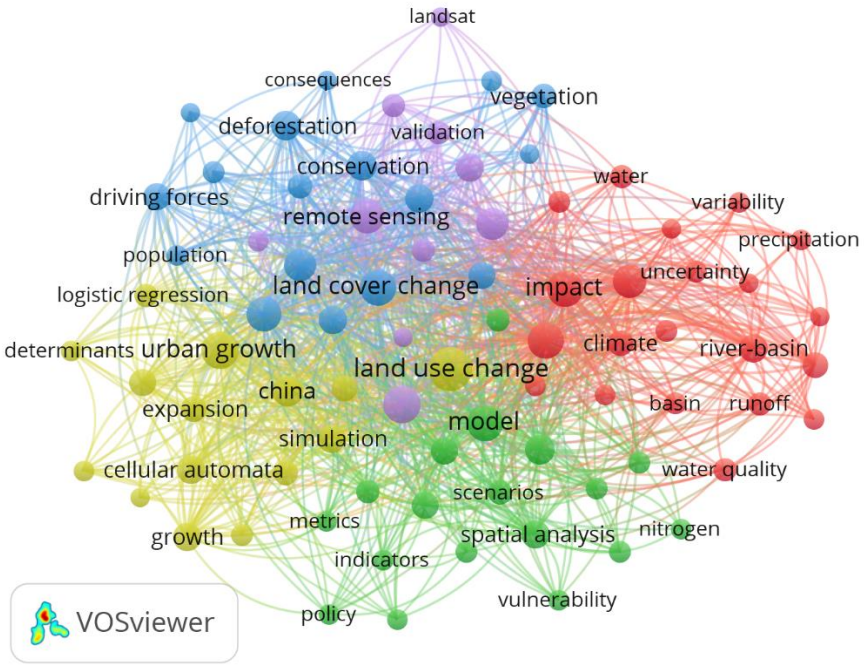


Figure 5. The 25-time keywords occurrence (fractional counting).

3.3.1. Land Use Change Trajectories, Flow, and Causes

The quantitative and qualitative assessment of where, when, and why local, regional, or global land cover changes have occurred has been a major research topic undertaken by many scientists. Over the past three decades, there has been an increase in the number of studies documenting land use changes in an explicit spatial manner, especially urbanization and agricultural intensification, as well as the consequences of these processes, such as deforestation and loss of agricultural land. Descriptive studies of land use change are generally indispensable as a first step towards more refined GIS spatial analyses.

Urbanization, as a complex and continuous worldwide process that has been going on for hundreds of years, has been studied by many scientists, focusing on urban expansion, urban sprawl, and the dynamics and patterns of urbanization (see the keywords in the yellow cluster, Figure 5). Antrop and van Eetvelde [44] noted that urbanization entails diverse and complex changes to the rural landscape in the vicinity of cities and towns, leading to very heterogeneous landscapes. Gerten et al. [45] observed that the trend of urbanization is predicted to remain stable in the future and would affect land use patterns in many ways. Furthermore, Keil [46] stated that the Earth is the "suburban planet" and anticipated that people are trying to "make the world urban from the outside in". The European Environmental Agency (EEA) [47] warned that urbanization is irreversible, leads to waste soil resources, fragments the landscape, and reduces the potential of ecosystems to provide important ecological services. The level and dynamics of urbanization vary greatly around the world. Henderson and Turner [48] found that Europe, North and Latin America, and the Caribbean, as well as West Asia, seemed to be fully urbanized. The share of the population living in urban areas accounted for more than 68%, with most regions nearing 80%. Chinese scientists have recently observed a noticeable and uneven urban development in some parts of the country, especially Benjin [29,49], Nanjing [50], Zhujiang Delta [41], and Yangtze River [36]. Moghadamab and Helbicha [51] found that, in Mumbai, the dynamics of urban expansion altered significantly over time, with the highest rate of urban growth of 142% occurring in 1973–1990, dropping to 40% in 1990–2001, and, finally, between 2001 and 2010, this fell to 38%. Persistent urban expansion and agriculture intensification, as well as agricultural land abandonment, were identified as the main processes of land use transformation in Europe [13,34,47,52].

Many scientists have reported on the economic consequences of urban expansion, e.g., Delbecq and Florax [53] or Nuissl and Rink [54] showed that urban sprawl increases land rent and leads to an upsurge in fallow land on the outskirts of urban areas, which are often transformed into open recreational spaces. Easterlin et al. [55] noticed that urbanization affects an individual's well-being in numerous ways, both positively and negatively, and Navarro et al. [56] added that as a "whole, the impact of urbanization on human well-being is unclear and it appears to be ultimately an empirical issue". In Java, an island of Indonesia, population pressure has caused agricultural land use expansion and intensification, as well as the conversion of prime agricultural land into residential and industrial areas [57]. Similar processes were observed in China and Mediterranean coastal regions [34,50,52]. In Central and Eastern Europe, great changes in land use occurred at the turn of the 20th and 21st centuries, after the collapse of socialism and radical changes in the political situation, especially the transition from a state economy to a market economy [58–61]. Land abandonment, urban expansion, and uncontrolled urban development, as well as changes in forest cover, were a noticeable reaction to this political and socio-economic situation.

The scientific community agreed that land use change is caused by many processes, both geographic and socio-economic. Moreover, a combination of biophysical, cultural, and economic drivers act differently depending on the scale [8,10,39,50]. Among geographical features, the distance to roads and commercial centers were analyzed in line with the van Thunen location theory [58,62]. Furthermore, the influence of the slope, soil productivity, annual precipitation, topographic position were also considered according to the Tobler's first law of geography [50,61,63–65].

As revealed by the analysis of citations and keywords (see blue cluster, Figure 5), the holistic approach to landscape ecology, where the landscape is considered as a complex whole that is more than just the sum of its composing parts [44], is a very noticeable part of spatially-explicit modeling of land use change. Among them, the assessment and mapping of ecosystem services have become a hot topic and an emerging global research trend since the beginning of the 21st century. The analysis of ecosystem services contributes to understanding the supply and demand of services, supports stakeholders in decision-making, and informs political priorities for environmental sustainability [66]. De Groot et al. [37] presented an overview of challenges related to the assessment and valuation of ecosystem services in environmental management and discussed some solutions leading to a comprehensive and practical framework for the ecosystem services' evaluation. The authors analyzed trade-offs involved in land cover and land use change, especially focusing on spatial analyses, dynamic modeling, as well as issues of scale referred to the physical dimension, in space or time, of observed land cover/land use. Concluding their research, they noted that some issues related to ecosystem services require a modification in environmental management priorities and related policies, especially with regard to current and future land use. Their findings were considered by researches of utmost importance; hence, the paper [37] received 1443 citations in the space of 10 years.

Satellite imagery, aerial photographs, topographic maps, and land cover/land use datasets based on remotely sensed data were the main sources of land use change inventory. Researchers emphasized that the synergy of GIS and remote sensing allows for an effective representation of LUC regardless of the scale and region of the research. Among the satellite data used, imagery from the Landsat (MSS, TM, ETM+) dominates [41,47,51,59,67,68], followed by Ikonos [58], MODIS [69], Sentinel, and IRS [59,61]. Remotely sensed data, i.e., aerial photographs and satellite imagery, has proved to be a valuable tool, not only to inventorying and monitoring land use changes but also for describing complex aspects of heterogeneous landscapes, as reflected in the image pattern [43,44,50]. The imagery interpretation was often supported by topographic maps [66,67,70,71] and aerial photographs [40,44,61]. Moreover, many GIS layers are easily accessible to model land use/land cover changes. Since the 1990s, several land use/land cover datasets were developed based on satellite image classification, including: CORINE land cover multi-temporal European datasets, delivered by EEA and Copernicus land monitoring services [59,61,70,72], Global Historical Land-Cover Change Land-Use Conversions (GCLCs) available at NOAA web services [73], and Globeland-30 provided by the National Geomatics Center of China [74]. All of them are of relatively high thematic accuracy rates: 93.8% for GCLCs, 90.6% for Globeland-30, and 89% for CORINE land cover, as stated by Reference [74]. The synergy of geographic information (vector and raster), remotely sensed data, and historical maps for land-use change modeling has been highlighted by many authors, including Statuto et al. [70–72]. The authors developed a methodology for land-use change analysis and applied it to the forest-agricultural landscape of the Mediterranean region. Nevertheless, the method is universal and has made it possible to study the landscape from different points of view and to carry out a multi-temporal and interdisciplinary analysis both in the short and long terms.

3.3.2. Consequences of Land Use Changes

The relationships between land use change with environmental and ecosystem changes, including climate, soil, water and ecosystem services, vary depending on the scale of the research. However, as noted by Geist and Lambin [5], globalization implies functional relationships between land use changes in remote locations. Many studies have documented that land use change in a particular geographic location was deeply shaped by land use policies in other spatially distant areas [6,8,10,35,38,58,63]. De Groot et al. [37] and Seto et al. [6] observed that, at a global scale, human-induced land use change leads to carbon sequestration and climate changed through the regulation of albedo, temperature, and rainfall patterns.

On a regional or continental scale, changes in land use cause fluctuations in river and groundwater flow, soil erosion and loss, and biodiversity fragmentation, while, at a local level, it is: water and soil

pollution, and extreme weather events (floods, storms, drought). Many studies have noted that spatial analyses of land use changes, and especially their impact on future land use patterns and hydrological processes at the watershed level, are essential in monitoring, planning, and managing water resources.

Land cover degradation through erosion, overgrazing, desertification, salinization and acidification, was considered a major environmental problem [6,8,32,42,74]. However, as noted by Houghton [75], while the effects of land use modification are small at the local level (e.g., agriculture intensification by using fertilizers), their cumulative effect on a regional or global scale may be significant (i.e., significant contribution to global emissions of nitrous oxide and concentrations of greenhouse gases). Lin et al. [76] revealed that the variability and size of future hydrological components were substantially and cumulatively influenced by land use changes, especially runoff and groundwater discharge. Based on a Texas case study, Sun et al. [77] concluded that climate changes had the most noticeable impact on regional water supply and demand, while, predicted land use and land cover changes will have a slight influence on both water quantity and the water supply-demand relationship. The study conducted by Du et al. [78] revealed that annual runoff, daily peak flow, and flood volume of the Qinhuai River watershed in the Jiangsu Province (China) have increased and will continue to increase as urban areas upsurge in the future. Similar conclusions were made by Tang et al. [79] who noticed the watershed would likely be subjected to impacts from urbanization on runoff and some types of non-point source pollution. Moreover, they found that increase runoff volume depends on the development rate.

The overall impact of land use/land cover change on climate change and environmental management strategies were broadly discussed by Solecki and Oliveri [80]. The authors indicated that the 'difference in the urban extent and, in turn, in the vegetative fraction could have a significant impact on possible future air quality conditions in the New York Metropolitan Region particularly with respect to ozone concentrations'.

3.3.3. Prediction of Future Land Use Software and Applications

The land use changes predictive models presented in the literature vary considerably. Most of them are based on deterministic approaches focused solely on one type of land flow, i.e., deforestation, urbanization, and loss of agricultural land. As noted by Lambin [31], they tailored the investigation method to the particular research question. Many articles provide an in-depth analysis of land use change models, as well as an overview of the available software packages for running these models [16–20,65]. Several publications contain also extensive analyses of the advantages and limitations of tools that implement a spatially explicit LUC model [16,17,31,81]. The complexity of land use change modeling resulted in a wide variety of approaches implemented. Models vary depending on the goals, assumptions, modeling strategies and computational approaches, the geographic areas of the analysis, and the data used [17,65]. Moreover, the scale of modeling is extremely important, as the global models cannot be used beyond the resolution of individual countries. This is because driving factors are generally region-specific and land use expresses local variations in geographic and socioeconomic conditions [82]. The general LUC model categories distinguished by Michetti and Zampieri [17] are: geographic, economic, and linked models. The strength of geographic models lies in depicting the spatial dimension and biophysical constraints of land use change, while constraints arise from a lack of consideration of socio-economic factors, endogenous land use change factors and, finally, a lack of climate and economic system feedback. Economic models, according to the authors of Reference [17], do not take into account spatial disparities in biophysical land use because land use allocation is exclusively driven by market structure. The linked models represent more advanced tools because, by considering the economy and the geosphere in one framework, they are able to take into account human and geographic feedbacks, and, finally, they can analyze land use changes over the long-term scale, at any geographic area, from local to global [17,65,81].

The bibliometric analysis showed that the CLUE, SLEUTH (Slope, Land cover, Exclusion, Urbanization, Transportation, and Hill-shade), DINAMICA EGO (Environment for Geoprocessing

Objects), and IMAGE model families were more frequently used when considering GIS spatial analysis for land use change, followed by integrated, complex, and linked LUC models [16,17,65]. CLUE (Conversion of Land Use and its Effects) was developed at the Wageningen Agricultural University (Netherlands) is a statistical simulation model that operates at a regional scale and accounts for multiple land use types as a function of their driving factors [28]. The prediction time span ranges from 20 to 40 years. The CLUE model was applied to analyze and predict land use changed in Europe [81], Java [57], Taiwan [75], Malesia [28], and many others. The SLEUTH urban growth and land use change model uses a probabilistic cellular automata (CA) protocol for simulating complex urban land use changes based on remotely sensed data [80]. It is one of the most well-known CA models in the field, with two decades of experiments documented in the literature [83] and was tested in urban areas in China, Africa, North and South America. The possibility of the model to perform self-modification of its parameters is essential in adjusted SLEUTH to a particular geographical area and to control the temporal urban growth rate during model calibration and urban growth prediction [83,84]. However, the study conducted by Herold et al [84] revealed the need to analyze the sensitivity of the SLEUTH model parameters as they have a critical impact on the simulation results, especially in areas where built-up units are small, heterogeneous and dispersed. DINAMICA was developed in 2002 by Soares-Filho et al. [85] to simulate forest changes in the Amazonian region during the last decades of 20th century, and finally became a prototype for the Dinamica EGO model elaboration, a cellular automaton model that uses Weights of Evidence and two mechanisms (patcher and expander) to obtain potential change maps and new LUC scenarios [86]. The model was successfully applied in deforestation, agricultural abandonment, and urban growth studies [85–87]. Its main strength lies in the outstanding possibilities of a multi-region and multi-scale approach and the inclusion of decision-making processes in the analysis and simulation of land use. IMAGE is an example of Integrated Assessment Models (IAM) that aim to synergize human activity, decision-making and environmental impact [17,65,81]. IMAGE is a standalone software package, dedicated to dynamic, global modeling (up to 2100) multiple land use types, however, with particular attention on agriculture and livestock [17,87]. The IMAGE package integrates land cover, vegetation, and economic models together with the climate system. The software was used, inter alia, for analysis of the future dynamics of European land use. The explicit spatial context of land use prediction was achieved by integration with one of the geographic LUC models, such as CLUE-S [81].

Despite the many LUC models available as standalone software packages or models embedded in GIS tools (e.g., CA_MARKOV and Land Change Modeler available from IDRISI [16]), scientists analyzed land use change dynamics by incorporating multiple tailored algorithms based on regression analyses, Markov chains, cellular automata, artificial intelligence, deep learning, and agent-based modeling or coupling of some of them. The strength and limitations of the above approaches were reported by Noszczyk [65], while Michetti and Zampieri [17] discussed, inter alia, integrated assessment models (IAMs), which are composed of submodules and are able to communicate through data and result exchange. As the most advanced IAMs, they could explicitly consider climate change, as well as the economics and biophysics of the land system, and simulate the future land use changing scenarios at global long-term scale. Moreover, this group of LUM allows scientists and policymakers to understand drivers and impacts of land use change, as well as to discourse the synergy and trade-offs of different land use strategies. Notwithstanding the many advantages, the integrated assessment models require a huge computing power, which entails a high degree of complexity. Besides, the interrelationships between the various sub-models and the complexity of relationships between drivers and past and future land use make the uncertainty analysis very difficult, which was pointed out by Reference [88].

4. Discussion

A large number of scientific publications on GIS spatial analysis modeling for land use change indicate some semantic uncertainties that require further discussion. These are ontological plasticity of land cover and land use concepts and understanding the spatial context of land use change analysis,

as well as the scale of the investigations. Moreover, the geosciences theories behind the land use change analysis and modeling also need some explanation.

Land cover and land use are fundamentally different concepts of the land surface. Land cover is defined as the physical state of the land surface, while land use is a description of the spatial aspects of all human activities on the land [8,89]. As noted by Fisher et al. [90], 'land cover is determined by direct observation while land use requires socio-economic interpretation of the activities that take place on that surface'. The differences in concepts were acknowledged in many papers (as an example, Reference [8,17,59]). The unclear definitions of land use and land cover concepts cause many interpretation problems during data integration from various datasets, especially those remotely sensed [8,90]. Land may be designated for single-use and also used for multiple purposes that cannot be determined from remote sensing data because many land use types share the same land cover [91], e.g., land covered with grass, it could serve as meadows, pastures, recreation, or sports and leisure. While the distinction between land use and land cover is relatively easy at a conceptual level, it is not as straightforward in practice as the available data tends to mix land cover and land use in one dataset. As found by Reference [90], the change from land use to land cover mapping was mainly a consequence of the automated processing of satellite imagery (also see keywords relatedness Figure 5). The ambiguity in the definitions of land use/cover classes revealed the need to develop rules for harmonizing concepts in order to achieve interoperability. An example of such an initiative is the INSPIRE (Infrastructure of spatial information in Europe) project aimed at creating an infrastructure for spatial information in Europe [92], in which the land cover and land use are treated as a separate set of spatial data, implemented on different principles.

Another interpretative problem relates to the method of determining the scale of the study, in particular the use of an adjective describing a local and global scale, e.g., large/broad or small/fine scale. Scale conceptualizes the level of detail of the research; hence, its importance in science is indisputable. The concept of scale comes from cartography and is based on the mathematical relationship (ratio) between the extent of the representation and that which it represents, a large scale means a small reduction in the area, and small scale the big reduction. Contrary, in geoscience the concept of scale refers to the relative size of the space covered by an analyzed process or geographical feature, like a problem space. Hence, the large-scale problems cover relatively large areas, while small scale problems cover small areas, so the scale of investigation is determined as small, medium, large, etc. In this sense, the relationships between scales (object sizes and phenomena) are opposite to those between different cartographic scales and the reference space. Moreover, the land use/land cover classifications or nomenclatures are generally scale-dependent, as they are tailored to the particular level of details distinguished in terms of the spatial scale of analysis for which they are developed and the purpose of their development.

The analysis of the literature showed that LUC models are classified as spatial and non-spatial [17,65,66,93]. This classification is based on the assumption that spatial models are those that relate directly to a specific location or geographical area. Nevertheless, according to the standards of the International Standardization Organization in the field of geographic information (ISO 19 100 series), the spatial reference has a broader context and also applies to areas or objects located implicitly associated with a location relative to the Earth, e.g., through a geographical name [94]. Therefore, to avoid confusion, Labmin el al. [3,7,8] use the term explicitly spatial, Michetti and Zampieri [17] geographical, and Briassoulis [93] pure-spatial.

The multitude of research related to spatial analyses of land use change is not without connection with broader theoretical and methodological changes in the disciplines that have contributed to this research, as well as in supporting IT (Information Technology), remote sensing, and GIS technology. One of them is undoubtedly the "quantitative revolution" in geography, economics, sociology and planning in the 1950–60s, the second "[93] data-driven science" in the late 1990s [95]. Among plenty of theory, that give the fundamentals of spatial analysis for land use change, some of them are of utmost importance, as they explicitly relate to geographical space. In economic-oriented models,

Von Thunen's agricultural land rent theory [58,62] and its refinement by Alonso urban land market theory [93] dominate. Both perform well at a local and regional scale. In the explicit spatial LUC model, Tobler's geographic laws (the first and the second laws) play an important role in establishing spatial relationships between past, present, and future land use, which can be seen in cellular automata, artificial network and rule-based modeling. Land use changes in urban areas were also modeled based on the concentric zone theory, radial sector theory, or multiple nuclei theory, all of them being the modification of von Thunen's assumptions [93].

5. Conclusions

Land use/land cover change is recognized as a global environmental and development problem, but, due to its complex nature and local occurrence, there is yet no consensus to quantify its global impact on environmental change, especially climate change. One of the most urgent challenges in land use change modeling is to consider both human and climate-induced changes and to estimate to what extent the latter is caused by human activities. Since the late 1990s, information on land use comes from readily available satellite imagery processed by many GIS-oriented software packages. Furthermore, satellite data allows for continuous monitoring of land use changes at a range of scales.

The bibliometric analysis reveals that GIS spatial analysis modeling for land use change is an interdisciplinary field of science, led by scientists from all over the world, whether they are specialists in natural, technical, or social sciences. However, so far, collaboration in this field is rather countrywide than international. The studies cover LUC spatial analysis at local, regional, and global levels. However, generally, investigations at particular spatial scales are conducted mostly in isolation from each other and often fall within just one science discipline (e.g., environmental sciences, ecology, geography, geosciences, urban, forestry).

The systematic literature review revealed that the conducted investigations are grouped into three main research streams, namely: documentary, explanatory, and predictive. Documentary (descriptive) research focused on the analysis of land use change, the depiction of land flows and trajectories, and identification of the causes and effects of land use changes. It also included a holistic view of landscape changes caused by land use, particularly landscape fragmentation, biodiversity loss, and ecosystem services. Descriptive studies of land use change are generally indispensable as a first step towards more refined GIS spatial analysis. Although, it is not enough to provide an understanding of the observed land use changes or to make decisions about effective ways to deal with the negative consequences of these changes. Explanatory studies attempt to fill this gap. Scientific documents, classified as explanatory, mainly dealt with the relationship between land use change and environmental or ecosystem changes, including climate, soil, water, and ecosystem services. Predictive research, on the other hand, was dedicated to simulating scenarios and forecasting future land use based on geographic and socio-economic factors.

Land use change approaches and models vary significantly, from the simplest ones to very advanced IAMs, and relate to geographical space directly (explicit) or indirectly, just by location to the investigated region by giving their geographical name. Different approaches to spatial modeling and analysis of land use changes and their impact on the environment give the big picture of the current research status and still unsolved issues. Hence, this study contributes to discourses about GIS-based land use change modeling and the drivers of land use change, as well consequences of these changes, and is expected to provoke more discussion on complex modeling approach starting from the assessment of current land use patterns and prediction land use changes in the form of multiple scenarios, as well as the impact of local land use change on the global ecosystem.

In the future, it is planned to extend analysis of state-of-the-art and trends of GIS spatial analysis modeling for land use change with research papers indexed in the SCOPUS abstract and citation database.

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