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Research Article

Bibliometric overview of the systems approach in Geomorphology production: journals Q1 and Q2, Earth-Surface Processes (SJR)

Panorama bibliométrico da abordagem sistêmica na produção em Geomorfologia: periódicos Q1 e Q2, Earth-Surface Processes (SJR)

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Abstract: In the 20th century, the systems approach was consolidated as an alternative in proposing scientific methods and models in Geomorphology, but what is the extent of its influence and how did the appropriation of these concepts by the discipline manifest itself? This research aimed to provide a historical overview of the impact of the systems approach on the production in Geomorphology based on the bibliometric analysis of 20 journals classified as Q1 and Q2 (Scimago Journal Rank — SJR 2019) in the Earth-Surface Processes category. Data from the Web of Science Core Collection were processed using VOSViewer and statistical tools, totaling a sample field of 1129 documents. The results brought to light similarities and differences, whether in the protagonism of countries, authors, and subfields of the discipline. In general, there was a scenario of growth in the use of terms and concepts related to the systems approach in Geomorphology and a significant conceptual distance, with the loss of referential links with the past. Thus, even far from the unitary and transdisciplinary science idealized by Ludwig von Bertalanffy, systems approaches have been consolidated as part of the work of geomorphologists and geoscientists for decades, strongly driven by the use of models and quantitative methods.

Keywords: systems thinking, complexity, Geomorphology, bibliometrics, VOSviewer.

Resumo: No século XX, a abordagem sistêmica se consolidou como alternativa à abordagem reducionista na proposição de métodos e modelos científicos em Geomorfologia, mas qual a dimensão de sua influência e como se manifestou a apropriação destes conceitos pela disciplina? Esta pesquisa objetivou realizar um panorama histórico da influência da abordagem sistêmica na produção em Geomorfologia a partir da análise bibliométrica de 20 periódicos classificados como Q1 e Q2 (*Scimago Journal Rank* — SJR 2019) na categoria *Earth-Surface Processes*. Os dados provenientes do *Web of Science Core Collection* foram trabalhados com o uso do *VOSViewer* e ferramentas de estatística, totalizando um campo amostral de 1129 documentos. Os resultados obtidos trouxeram à tona similaridades e diferenças, seja no protagonismo de países, autores e subcampos da disciplina. De modo geral, constatou-se um cenário de crescimento do emprego de termos e conceitos correlatos à abordagem sistêmica na Geomorfologia e um significativo distanciamento conceitual, com a perda de elos referenciais com o passado. Assim, mesmo distante do cenário idealizado por Ludwig von Bertalanffy, de uma ciência unitária e transdisciplinar, as abordagens sistêmicas consolidaram-se como parte do trabalho dos geomorfólogos e geocientistas há décadas, fortemente impulsionada pelo uso de modelos e métodos quantitativos.

Palavras-chave: abordagem sistêmica, complexidade, Geomorfologia, bibliometria, VOSviewer.

1. Introduction

In the second half of the 20th century, the systems approach became established as an alternative to the reductionism that was enshrined by Descartes (1596–1650) in the 17th century, aiding the proposition of new scientific methods and models. Its contribution to Earth Sciences, particularly to Geomorphology, also deserves recognition given its recurring presence in scientific production, influencing methodologies, or even the approach to specific research problems. In this context, a question arises: is it possible to measure the methodological influence resulting from the publication of *General System Theory* (BERTALANFFY, 1968) and other foundational works of the systemic approach in Geomorphology scientific production?

Specifically, methodological influence is understood as the direct (referenced) or indirect (non-referenced) application of the concepts and assumptions of the systems approach in scientific documents within the field of Geomorphology. In terms of definition, the systems approach is a simplified nomenclature for a broad range of scientific methodologies rooted in holistic principles, prioritizing a global observational scope. Interdisciplinary by nature, encompasses, for instance, the idea of a unified General Systems Theory or Systems Science proposed by Bertalanffy (1968). In synthesis, systems are composed of elements, connections, and functions that can be analyzed integrally. The systems approach may also be referred to as Complexity Sciences, aiming to encompass its broad and diverse theorization and application across different scientific fields (MITCHELL, 2009; CASTELLANI, 2018).

Around the main question, others may arise, such as: which subfields of Geomorphology most adopt key concepts of the systems approach? Which authors and works influenced by the systems approach have been most impactful in different subfields of Geomorphology? What is the conceptual distance between the use of these concepts in recent scientific production and their classical definition present in foundational literature? It is expected that, despite increasing records of the use of keywords related to the systemic approach in Geomorphology and Physical Geography production, the methodological proposals exhibit some conceptual distancing from the original terms, within a context of constant interdisciplinary influences.

Therefore, this research aimed to provide a historical overview of the influence of the systems approach, in its various manifestations, on production in Earth Sciences and, particularly, in the field of Geomorphology, based on a bibliometric analysis of 20 journals classified as Q1 and Q2 (*Scimago Journal Rank* — SJR 2019) in the *Earth-Surface Processes* category. Possibly, not all questions can be fully answered here, but it is hoped that this work will serve as a basis for more in-depth discussions on the subject.

2. Materials and Methods

To achieve the objective of the present study, three methodological stages were established, described in detail below:

Delimitation of key concepts of the systems approach (Stage 1):

A bibliographic (qualitative) analysis was conducted based on reference documents on the systems approach, aiming to identify the key concepts that characterize it as a distinct methodological and scientific thinking trend in the 20th and 21st centuries.

In this initial stage, the key concepts of the systems approach were identified through a qualitative bibliographic review. These terms were subsequently employed as the main variables in the data collection for quantitative bibliometric analysis.

Considering the extensive range of publications presenting concepts of the systems approach across numerous scientific fields (see Castellani's phylogenetic tree, 2018), two main publications were selected as reference for identifying the key concepts: *General System Theory: Foundations, Development, Applications* (BERTALANFFY, 1968) and *Complexity: A Guided Tour* (MITCHELL, 2009).

The selection of these specific publications was based on three main reasons. First, they are internationally recognized reference works regarding the conceptualization of Systems and Complexity Sciences, with universal, interdisciplinary, and conceptual scopes. Second, they represent two distinct moments in the discussion on the topic, influenced by specific historical, geopolitical, technological, and methodological contexts. Finally, the highlighted publications reflect the natural evolution of a single research problem, albeit with distinct methodologies, theoretical foundations, and applications. Thus, an effort was made to identify in both works the recurring concepts within the theoretical foundations of their proposals, as well as their similarities and differences in the use of these terms.

Other bibliographies were also consulted to compare the meanings of terms whenever necessary, such as: *Modelagem de Sistemas Ambientais* (CHRISTOFOLETTI, 1999), *Thinking in Systems: A Primer* (MEADOWS, 2008), *Inteligência da Complexidade. Epistemologia e Pragmática* (MORIN; MOIGNE, 2009), and *The Basics of Geomorphology: Key Concepts* (LEWIN; GREGORY, 2014).

After the bibliographic review, the main concepts selected to support the bibliometric research stage were: system, complexity, nonlinearity, hierarchy, self-organization, chaos, resilience, equifinality, feedback loop, and complex/dynamic/adaptive/open systems, along with concepts related to prognosis and modeling (see the search routine in Table 1).

<u>Recognition of historical patterns in scientific production in Geomorphology influenced by the systems approach (Stage 2):</u>

A bibliometric (quantitative) analysis was conducted to identify the use of key concepts of the systems approach in publications from leading journals in Geomorphology.

To measure and quantify the number of publications in Geomorphology influenced by the foundations of the systemic approach, bibliometric methods were used based on the occurrence of keywords in preselected journals. This stage aimed to: identify the use of systems approach concepts in Geomorphology journal publications; and statistically delineate the frequency of occurrences, temporal trends, the most recurring authors/works, and the subfields with the highest occurrences of related concepts.

The scope of observation was restricted to scientific output in internationally recognized journals in Geomorphology, following the *Scimago Journal Rank* — SJR (Scopus/Elsevier) classification Q1 and Q2 (2019 assessment). The analysis was restricted to journals classified within the *Earth and Planetary Sciences*, *Earth-Surface Processes* category (SJR), comprising the top ten of Q1 and Q2 journals (see journal list in Table 2). The choice of the top ten journals in each quartile aimed to limit the sample size, which was already extensive for research of this nature. The use of a classification like SJR aimed to reduce subjectivity in the researcher's journal selection, despite limitations in representativeness in impact factor-based categorization.

For each journal, a complete search routine was individually conducted, comprising 20 search lines in the *Web of Science* search prompt (Table 1). The search used field tags (indicating specific publication characteristics to be considered) and Boolean operators. Only documents published up to 2020 were included, imposing a well-defined temporal limit on the sample. Since new bibliographic metadata is continuously indexed in the platform's database, a clear temporal scale was necessary to ensure replicability.

The graphical representation of bibliometric maps was based on raw data (text file format) exported from the *Web of Science Core Collection*. Subsequently, VOSViewer v1.6.16 (Leiden University) software was used for graphic data analysis. The software spatially organizes data on the graph, where distances indicate thematic affinities among authors and research objectives, while representation sizes reflect their relevance in terms of citations within the sample universe.

For this application, the software's default configuration was used, with a routine that included analyses of co-authorship, keyword co-occurrence, citation, bibliographic coupling (authors and countries), and co-citation. Quantitatively, repeated occurrences of authors were considered regardless of whether they were first authors or not. Thus, the fractional counting method, which assigns proportional weights to relationships between publications, was not applied. This choice assumes that repeated author occurrences may help identify individuals with significant contributions to the discipline's scientific output.

Complementary to the scientometric map, descriptive statistical analyses were conducted to better represent the identified trends over the sample period, especially through occurrence graphs that consider temporal and country-of-origin aspects. The results from this stage were summarized using Microsoft Excel, covering general quantitative descriptive characteristics (concept usage occurrences, temporal distribution, and variation trends) and qualitative characteristics (identification of the most recurring authors, countries, and areas).

Despite the effort to represent the main historical trends in the use of key concepts, it is important to note that the Web of Science Core Collection originally fully indexes abstracts and keywords only for articles published since the 1990s, requiring continuous updates to metadata for older articles. When abstracts and author keywords are missing in metadata, searches only capture the presence of the search term in the title, leading to an underestimation of occurrences before that. In summary, there is no full indexing of articles predating the 1990s, a limitation of databases that are progressively incorporating older documents into their core collection.

Categorization of different levels of appropriation of systems approach key concepts in Geomorphology (Stage 3):

Selection of standout works from the previous investigation stage and qualitative categorization of different application patterns of systems approach key concepts.

To go beyond the mere quantitative characterization of publications, a qualitative analysis was conducted, considering the ten most-cited articles from each analyzed journal. This analysis aimed to classify whether the articles truly align with the premises of the systems approach. The articles were categorized based on abstract readings into the following categories:

- Low affinity: no relation to the systems approach's theoretical framework.
- Medium affinity: application of methods related to the systems approach without direct references to obviously related works, concepts, or authors.
- High affinity: application of methods related to the systems approach, with direct references.
- Excellent affinity: systems and/or complexity theory forms the conceptual framework and goal of the entire publication, discussing the historical and conceptual evolution of the discipline.

This classification stage for each journal’s publications was essential to deepen the quantitative data derived from bibliometric research and mapping. It also allowed for assessing whether the employed search method captured different levels of systems approach influence in the selected journals.

3. Results

In this section, the results of bibliometric research using predetermined key concepts are presented. The search criteria applied involved 20 search command lines for each analysis, as shown in Table 1.

Table 1. Search criteria: top ten journals classified as Q1 and Q2 in the field of *Earth and Planetary Sciences* and the category *Earth-Surface Processes* (SJR, 2019). This example presents the results for the journal *Earth Surface Dynamics* (ISSN 21966311 and 2196632X) as a case study.

Routine	Search command in Web of Science – Earth Surface Dynamics	Result
	Specific search from predefined keywords	
#1	TS = (complexity AND system*) AND (IS = 21966311 OR IS = 2196632X)	9
#2	TS = (nonlinear* AND system*) AND (IS = 21966311 OR IS = 2196632X)	1
#3	TS = (hierarch* AND system*) AND (IS = 21966311 OR IS = 2196632X)	0
#4	TS = (self-organiz* AND system*) AND (IS = 21966311 OR IS = 2196632X)	3
#5	TS = (emergen* AND system*) AND (IS = 21966311 OR IS = 2196632X)	4
#6	TS = (chao* AND system*) AND (IS = 21966311 OR IS = 2196632X)	0
#7	TS = (resilien* AND system*) AND (IS = 21966311 OR IS = 2196632X)	3
#8	TS = (equifinality AND system*) AND (IS = 21966311 OR IS = 2196632X)	0
#9	TS = ("feedback loop*" AND system*) AND (IS = 21966311 OR IS = 2196632X)	0
#10	TS = ("complex system*" OR "dynamic* system*" OR "adaptive system*" OR "open system*" OR "system* boundar*" OR "complex network*" OR "dynamic* network*") AND (IS = 21966311 OR IS = 2196632X)	1
#11	TS = (bertalanffy OR "system* theor*" OR "system* science*" OR "system* thinking" OR "complexity sciences" OR "system* approach" OR geosystem*) AND (IS = 21966311 OR IS = 2196632X)	0

Comprehensive search using terms commonly related to systems		
#12	TS = ((forecast* OR prediction OR prognosis) AND system* AND model*) AND (IS = 21966311 OR IS = 2196632X)	5
#13	TS = (model* AND system*) AND (IS = 21966311 OR IS = 2196632X)	76
#14	IS = 21966311 OR IS = 2196632X	361
#19	TS = (model*) AND (IS = 21966311 OR IS = 2196632X)	246
Ratios and comparisons		
#15	sum of keywords usage 1 to 11: #11 OR #10 OR #9 OR #8 OR #7 OR #6 OR #5 OR #4 OR #3 OR #2 OR #1	19
#16	(sum #15 AND model* #13)	16
#20	(sum #15 AND model* #19)	16
#17	(sum #15 AND forecast* #12)	1
#18	(Brazil AND sum #15)	0
N = 19 de 361, 5%		

Table 2 lists the journals selected as the sample group. The general presentation of the results compares 10 journals classified as Q1 in the field *of Earth and Planetary Sciences* and the *Earth-Surface Processes* category of the SCImago Journal Rank (SJR, 2019) with 10 journals classified as Q2 under the same parameters. Specific cases deemed more representative of the scope of this research are discussed subsequently.

Regarding the year of publication of the documents sampled through bibliographic metadata research (Figure 1), there is a general trend of temporal growth in the number of published documents, both in the Q1 spectrum (A) and in Q2 (B). However, despite this general trend, annual variations in production, whether positive or negative, cannot be overlooked. While the selected Q1 journals reached a peak in their historical series in 2020, the last year included in the analysis, the same pattern was not observed for the Q2 journals: their peak occurred in 2017, followed by a decline of approximately 25% in the following year. Since then, there appears to be a trend towards stabilization, although below the recorded maximum.

Concerning older publications, the earliest document in the Q1 sample dates to 1962, whereas the oldest document in the Q2 sample is from 1983. It is worth noting, however, that there is no comprehensive indexing of articles prior to the 1990s, a limitation of the method previously discussed. Additionally, in Q1 journals, similarities were observed between the numbers of documents published at the beginning of the 1990s and 2010s. Meanwhile, Q2 journals showed a more gradual growth, potentially reflecting the presence of newer journals in this group.

Lastly, it is important to emphasize that the scales of the graphs below are not the same due to the significant difference in the sample size obtained for the top 10 Q1 journals compared to the top 10 Q2 journals. While the Q1 journal search yielded 902 documents, the Q2 journal results included 227 documents. This could indicate differences in publication rates among journals from different quartiles of the SJR classification. Nevertheless, further in-depth investigation would be necessary to better understand the actual causes of this observed phenomenon.

Table 2. List of selected journals for group 2, classified as Q1 and Q2 in the field of *Earth and Planetary Sciences* and *Earth-Surface Processes* category (SJR, 2019). Journals highlighted in yellow have scopes that better align with the research problem and are discussed in greater detail in the present study.

SJR, category Earth-Surface Processes, Q1 e Q2 (2019)					
SJR Q1	***Journal***		***N***	***ISSN***	***Scope***
1	Transactions of the Institute of British Geographers		40	00202754, 14755661	Geography
2	Cryosphere		43	19940416, 19940424	Glacial Environments
3	Antipode		25	00664812, 14678330	Geography
4	Soil and Tillage Research		152	1671987	Soil Science, Agriculture
5	Biogeosciences		144	17264189, 17264170	Ecology, Multidisciplinary Geosciences
6	Journal of Geophysical Research		312	01480227, 21562202	Multidisciplinary Geosciences
7	Annals of the American Association of Geographers		119	24694460, 24694452	Geography
8	Earth Surface Dynamics		19	2196632X, 21966311	Geology, Physical Geography
9	Biogeochemistry		38	01682563, 1573515X	Geology, Environmental Sciences
10	Journal of Applied Earth Observation and Geoinformation		10	15698432	Remote Sensing
SJR Q2	***Journal***		***N***	***ISSN***	***Scope***
37	Journal of Arid Environments		82	1095922X, 01401963	Arid Environments
38	Journal of Paleolimnology		24	09212728, 15730417	Limnology, Geology
39	Arctic, Antarctic, and Alpine Research		16	15230430, 19384246	Glacial Environments
40	Canadian Geographer		36	15410064, 00083658	Geography
41	Journal of Palaeogeography		2	20953836	Paleontology, Paleogeography
42	Hydrology		12	23065338	Water Resources
43	Soil Research		15	18386768, 1838675X	Soils
44	Journal of Arid Land		5	16746767, 21947783	Arid Environments
45	Geodinamica Acta		8	9853111	Multidisciplinary Geosciences
46	Geographical Research		27	17455863, 17455871	Geography
N = 1129 documents					

Regarding the region of origin of the documents, there is a clear predominance of countries from the so-called "geopolitical North," based on the established socioeconomic and geopolitical division. In a sample involving 77 countries for Q1 journals (Figure 2, A), the top five countries, in terms of published documents, were the United States (31%), England (10%), Germany (7%), Canada (6%), and France (5%). An exception appears in the sixth position with contributions from China (4%), a country still considered emerging, but which has made significant strides in recent decades, not only economically but also in scientific production (see Figure 2, A). Brazil is ranked 12th, with a total of 23 publications (1.7%).

It is important to note that the sum of country records (N = 1,339) exceeds the previously reported total of documents (N = 902). This discrepancy arises from the nature of the metadata provided by Web of Science, where a single document may have affiliations with multiple countries. Additionally, the dominance of documents published by the United States is noteworthy, with its count surpassing the combined total of all countries ranked 11th and below ("Others," 28%). A total of 77 countries contributed to the SJR Q1 sample.

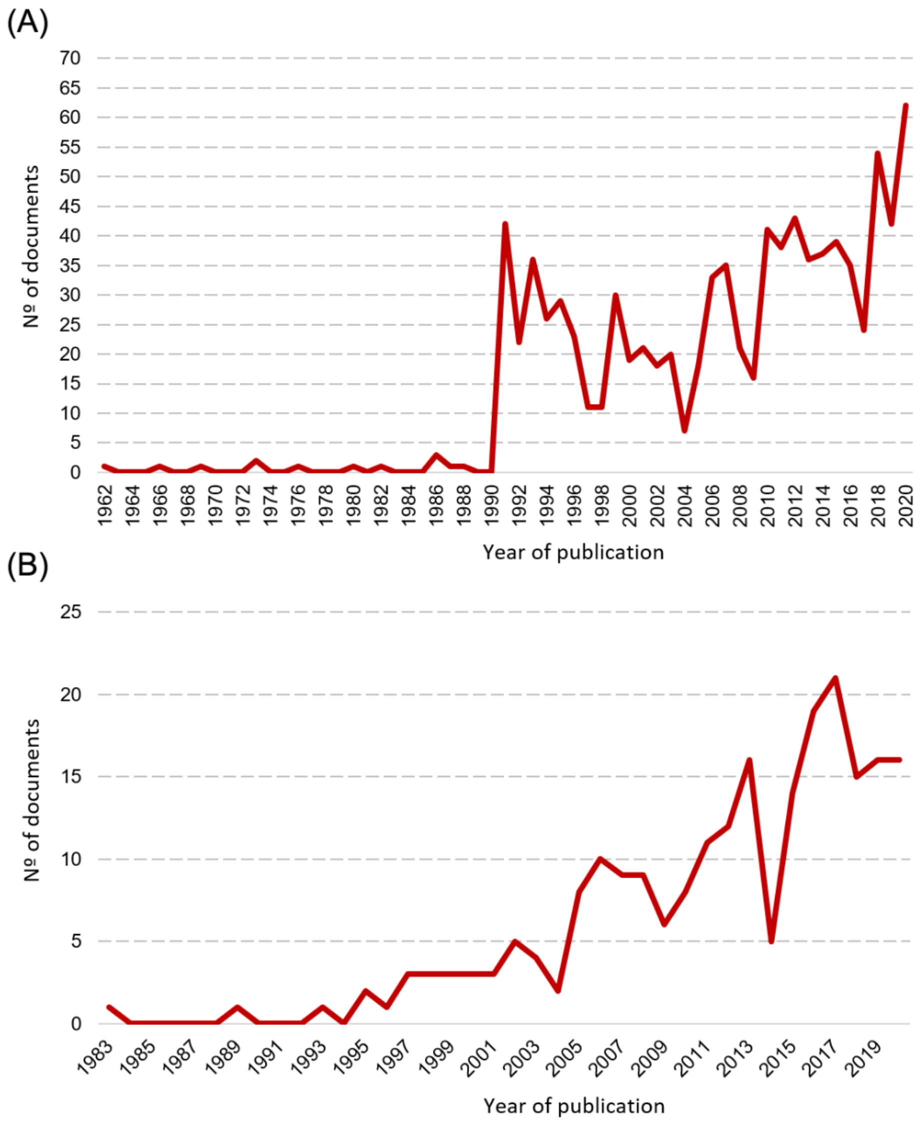

Figure 1. Temporal distribution of published documents from the top 10 Q1 journals (A, N = 902) and Q2 journals (B, N = 227) ranked by SJR in the *Earth and Planetary Sciences* field and the *Earth-Surface Processes* category. Source: data compiled from Web of Science and processed in *Microsoft Excel*.

A similar trend was observed for the top 10 journals classified as Q2 (Figure 2, B). The top five countries with the highest number of records are the United States (16%), Australia (13%), Canada (12%), France (9%), and England (7%). Once again, China ranks sixth, with 3%. Notably, among the top 10 countries, Argentina, a South American nation, stands out with 2% of the sample. Brazil appears again in the 12th position, with five publications (1.6%). As previously mentioned, the total number of country records was 306, out of a total of 227 documents. However, unlike the Q1 journal sample, the combined contributions from countries ranked 11th and below ("Others," 29%) are similar to the total of the top two ranked countries. A total of 53 countries had entries in the SJR Q2 sample.

Additionally, it is important to consider the host countries of the analyzed journals, shown in Table 2. Once again, from a geopolitical perspective, there is a predominance of "geopolitical North" countries, with six journals from the United Kingdom, four from the Netherlands, and three each from the United States and Germany, out of the 20 journals analyzed. The geographical, linguistic, and institutional ties between the countries publishing the documents and the host countries of the journals cannot be ignored, nor can the level of financial support for scientific research in these nations — a stark contrast compared to most emerging countries. Once again, the only exception is China, where the *Journal of Arid Land* ranks among the top 10 Q2 journals, positioned 44th in the 2019 SJR ranking.

From the general scope of scientific journals, the periodicals most closely associated with the research problem were selected, and their results are presented here. The individual sample description for each journal, its preliminary analysis, and the metadata exported from the Web of Science Core Collection, suitable for processing in VOSviewer, are available in the supplementary material of this publication.

In general, some journals were considered broad for addressing topics in both Physical and Human Geography (e.g., *Transactions of the Institute of British Geographers and Antipode*), while others were classified as specific to subfields of science (e.g., *Cryosphere* and *Journal of Arid Environments*) or belonging to other established sciences, such as Geology, Geophysics, Agronomy, and Environmental Sciences. Highly restricted samples with low sample sizes (fewer than 20 documents) were also deprioritized. The following journals were selected for result descriptions and discussions: *Biogeosciences* and *Annals of the American Association of Geographers* from the Q1 group, as well as *Geographical Research* from the Q2 group.

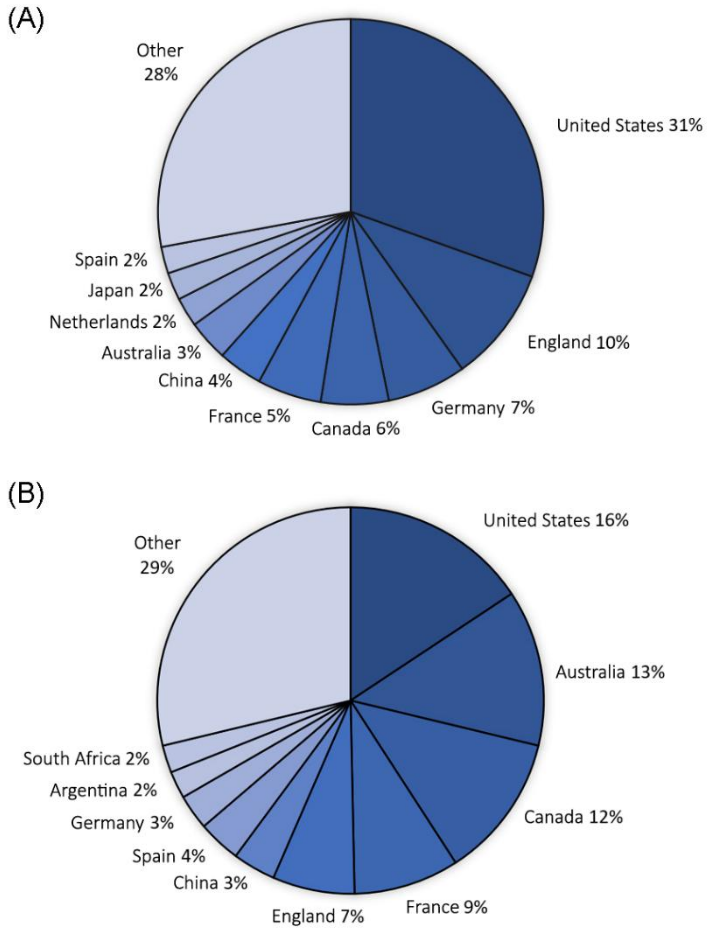

Figure 2. Distribution of published documents by country, considering the top 10 Q1 journals (A) and Q2 journals (B) ranked by SJR in the *Earth and Planetary Sciences* field and the *Earth-Surface Processes* category. Source: metadata from Web of Science exported via VOSViewer and processed in *Microsoft Excel*.

With a sample size of 144 documents (3% of the total documents in the journal), *Biogeosciences* is relatively recent, from 2004, with the first publication related to systemic approach terms dating back to 2006. All articles are open access. The highest annual publications in the sample occurred in 2016 (N = 16) and 2020 (N = 16), while the lowest was in 2006 (N = 1), the earliest record for the journal. There was a temporal increase in the use of the selected key concepts, followed by a decline with peaks, leading to a stable annual sample. The diversity of authors is significant, with a maximum of five publications per author. The most prolific authors are Brovkin (5), Frolicher (5), Joss (5), and several others with four documents each. Among the countries with the highest participation in documents are the United States (67), Germany (44), the United Kingdom (31), France (26), and Canada (22). Regarding language and nationality, the entire sample is written in English and represents 47 different countries. In South America, Brazil stands out with five publications, followed by Argentina and Chile with one each. In terms of affinity with systemic approach topics among the 10 most cited articles, medium affinity predominates (application of related but unreferenced methods), with highlights including *Improving land surface models with FLUXNET data* (WILLIAMS et al., 2009).

The search routine resulted in 119 documents (1.5% of the journal's total publications) from the *Annals of the American Association of Geographers*. Active since 1911, the oldest documents in the sample were from 1973 (N = 2), followed by 1982 (1), 1991 (1), and 1992 (1). This may reflect limitations in the Web of Science Core Collection for documents predating 1992. The peak in publications related to systemic approach terms was in 2020 (14), and the lowest, post-1990, occurred in 1996, 1999, and 2004 (N = 1). The general trend in publications using the key concepts appears to be increasing. Among the authors with the highest number of documents, Phillips (4) stands out, followed by An (3) and many authors with two documents. Among the countries, the United States dominates (84), followed by the United Kingdom (14), Canada (12), China (7), and Australia (6). With 28 countries represented, Brazil has two documents, Bolivia and Chile one document each. Regarding systems approach affinity, medium affinity dominated among the 10 most cited articles, with highlights including Stallins and Parker (2003): *The influence of complex systems interactions on barrier island dune vegetation pattern and process,* and Parker et al. (2003): *Multi-Agent Systems for the Simulation of Land-Use and Land-Cover Change: A Review.*

A total of 27 documents (3% of the journal's total) were recovered from *Geographical Research*, being the earliest publication from 2005 (N = 1), the journal's first year, with a peak in 2015 and observable gaps until 2020. The publication trend seems to be cyclical, with successive rises and falls in the number of publications. Few authors have more than one document, including Howitt (2) and McGuirk (2). Regarding countries, Australia stands out (19), followed by the United Kingdom (5) and several others with only one document. As with the previous journal samples, all are written in English, demonstrating Anglo-Saxon influence. Regarding affinity with the systemic approach among the 10 most cited articles, high and medium affinities predominate, with highlights including *Maps narratives and trails: Performativity, hodology and distributed knowledges in complex adaptive systems - An approach to emergent mapping* (TURNBULL, 2007).

The Web of Science metadata analysis was expanded using the VOSviewer v1.6.16 software. In this tool, co-authorship analysis indicated that 801 authors contributed to the *Biogeosciences* sample, with only 57 authors having two or more documents. For the *Annals of the American Association of Geographers,* 298 authors were part of the sample, of which only ten had more than two documents, with Phillips (N = 4) being an exception. Finally, *Geographical Research* had 70 authors in its sample, with only two having more than one document. In comparative means of co-authorship, a primary cluster was observed in the bibliometric map for the first two journals, with few isolated countries (Figure 3). This contrasts with the latter, likely influenced by its smaller sample size, fewer documents, and limited overall publication output.

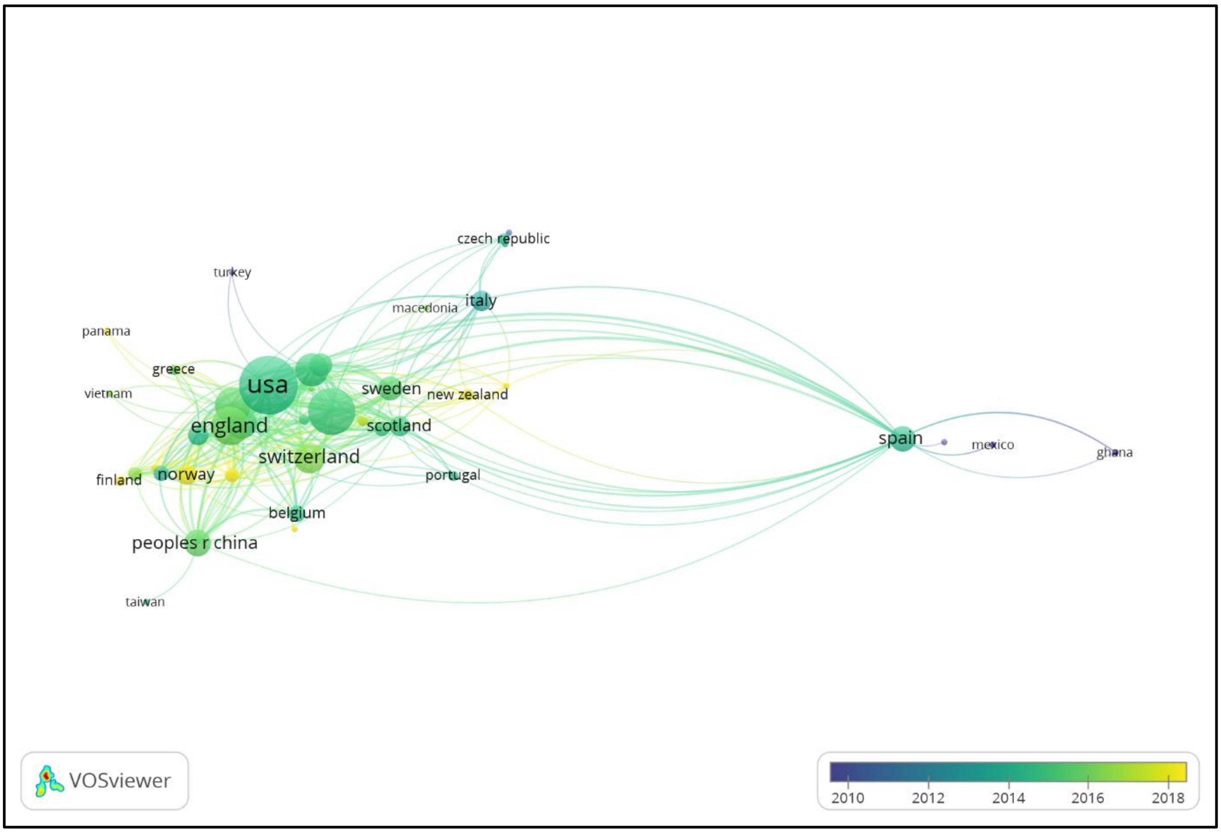

Figure 3. Co-authorship analysis of the journal *Biogeosciences*, considering the countries of origin. Note the direct and indirect connections across the entire sample. Source: VOSViewer.

In terms of keyword co-occurrence in the journal samples, 871 keywords were recorded in *Biogeosciences* (202 with double occurrences), 1,000 keywords in *Annals of the American Association of Geographers* (169 with double occurrences), and 239 keywords in *Geographical Research* (20 with double occurrences). Notably, indirectly related concepts from the systems approach appeared more frequently than the pre-selected key terms, indicating the diversity of the topic explored. Graphically representable (Figure 4), the highlights within the research scope were:

- *Biogeosciences* – climate change (24), variability (16), dynamics (16), earth system model (11), uncertainty (9), intermediate complexity (6);
- *Annals of the American Association of Geographers* – climate change (15), systems (10), scale (10), dynamics (9), vulnerability (9), resilience (9), adaptation (7), model (7), complexity (6);
- *Geographical Research* – resilience (6), systems (4), risk (4), geography (4), Australia (4).

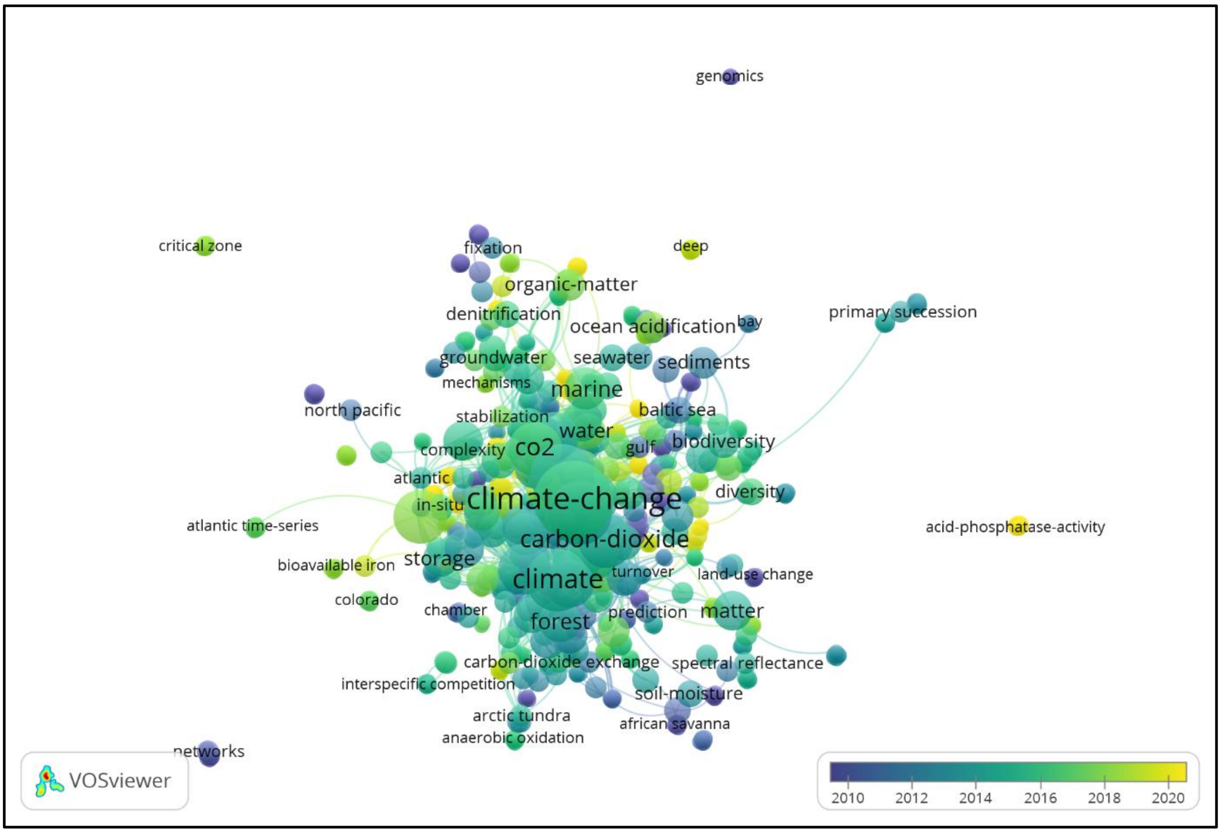

Figure 4. Co-occurrence analysis of keywords in the journal *Biogeosciences*. Note the high connectivity in the samples, demonstrating the relationships of use between keywords. Source: VOSViewer.

The co-citation analysis provided a robust range of data, even when working with a limited sample size. For *Biogeosciences*, the sample included 9,598 cited articles, with: 1,038 cited twice, 302 cited three times, and four cited at least 12 times. This formed two clusters—one principal and one restricted. The most cited documents were:

- Friedlingstein *et al.* (2006) "*Climate–carbon cycle feedback analysis: results from the C4MIP model intercomparison*" (20 citations);
- Bopp *et al.* (2013) "*Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models*" (12 citations);
- Sitch *et al.* (2003) "*Evaluation of ecosystem dynamics, plant geography and terrestrial carbon cycling in the LPJ dynamic global vegetation model*" (12 citations);
- Lloyd e Taylor (1994) "*On the temperature dependence of soil respiration*" (12 citations);
- Wanninkhof (1992) "*Relationship between wind speed and gas exchange over the ocean*" (11 citations).

Regarding the authorship, the scenario changes. The dataset comprises 6,441 authors, with 20 cited at least 12 times. This indicates a strong co-citation pattern within *Biogeosciences*, shaping "invisible colleges" (groups of researchers who collaborate without necessarily being part of the same institutional core). The most cited authors were Friedlingstein (30), Dickson (30), Le Quéré (27), Bopp (26), and Doney (25), forming a principal cluster (Figure 5).

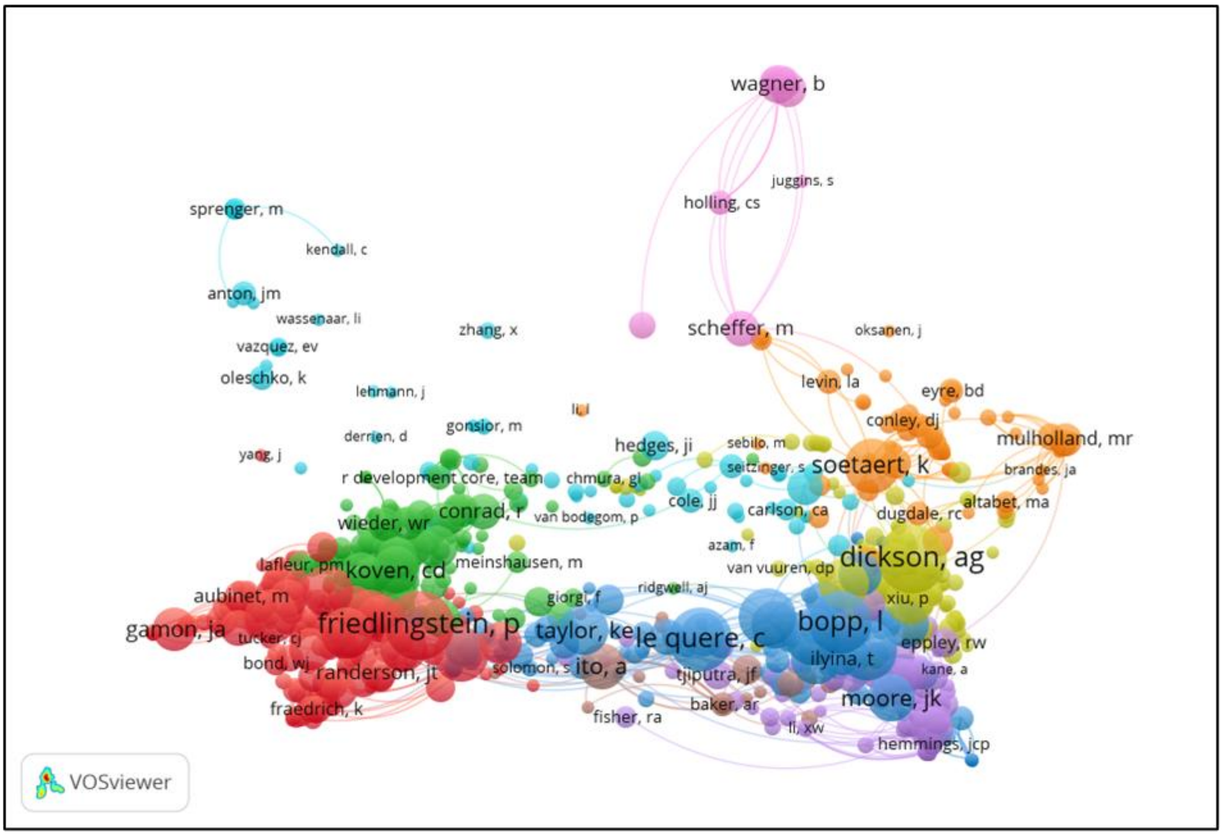

Figure 5. Author co-citation in *Biogeosciences*. Note the formation of interconnected cores and the low overall isolation, representing co-citation relationships between authors within the sample documents. Source: VOSViewer.

For *Annals of the American Association of Geographers*, the co-citation analysis identified 8,538 cited documents in a heterogeneous context, as only: 434 were cited twice, 76 were cited three times, and four were cited at least five times. The largest cluster included 104 items, followed by a smaller one with approximately 50 items. Notably, Harvey's 1996 publication, a seminal work in Human Geography, was present. This finding does not necessarily indicate an error in sampling but reflects the interdisciplinary nature of the dataset. To remain methodologically faithful, publications and journals not directly related to Geomorphology were retained and analyzed. Key highlighted works in this sample include:

- Parker *et al.* (2003) "*Multi-agent systems for the simulation of land-use and land-cover change: a review*" (7 citations);
- Malanson (1999) "*Considering complexity*" (7 citations);
- Harvey (1996) "*Justice, nature and the geography of difference*" (5 citations);
- Blaikie e Brookfield (1987) "*Land degradation and society*" (5 citations).

Concerning the co-citation of authors in the sample of the journal *Annals of the American Association of Geographers*, the analysis identified 6,124 authors, 1,231 of them with two citations, and 535 with three citations. Highlights include Phillips (47), Turner (34), Kwan (30), Cutter (29), and Batty (28). The largest cluster comprises 103 items, connected with other authors, such as Turner and Siemens (Figure 6).

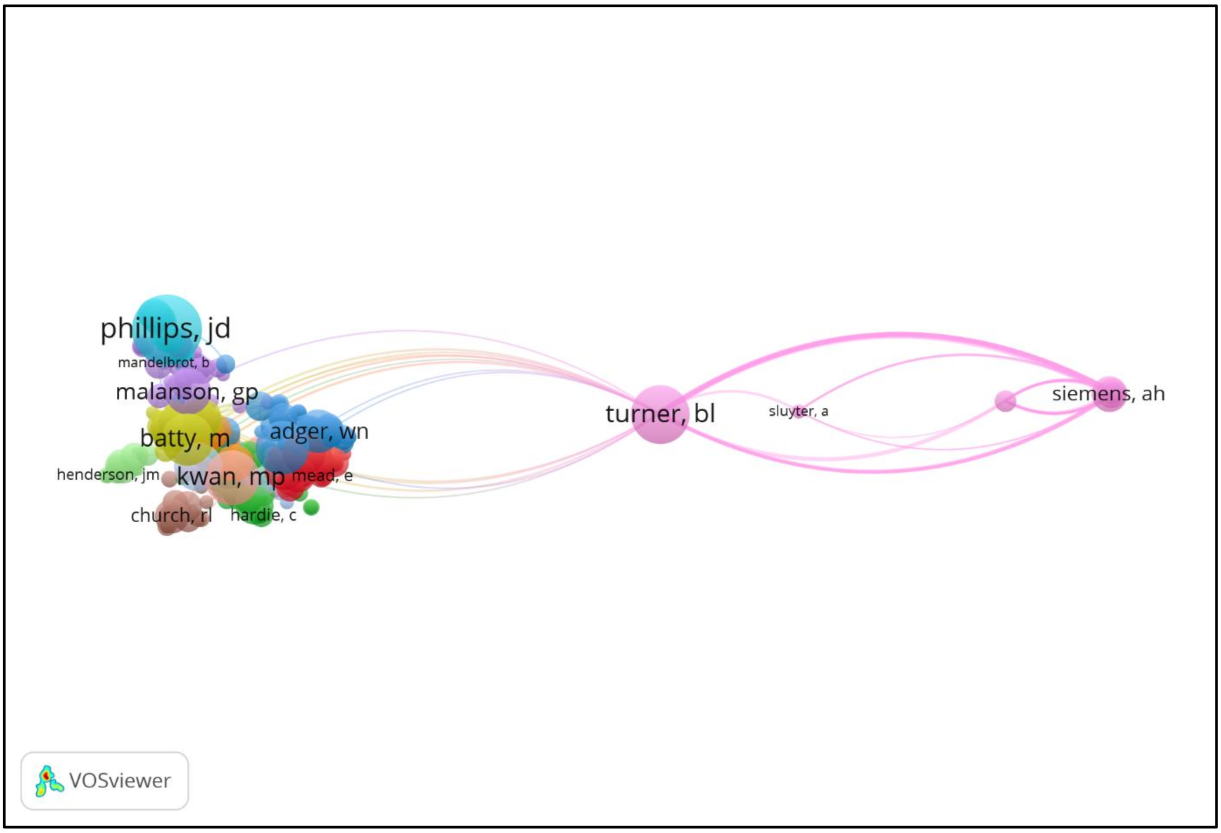

Figure 6. Co-citation of authors in the *Annals of the American Association of Geographers*. Note that the cores appear less defined compared to the previous case. Source: VOSViewer.

The document co-citation analysis in *Geographical Research* highlighted 1,573 cited documents, 17 of which had two or more citations, and only two had three citations: Folke et al. (2002), *"Resilience and sustainable development: building adaptive capacity in a world of transformations"* and Adger (2006), *"Vulnerability"*. In the graphical representation, a main core formation and low isolation are noted, with the largest cluster comprising 162 items. Regarding author co-citation, 1,212 names form the sample, 176 with two citations, 71 with three, 36 with four, and 3 with twelve or more. Highlights include Short (32), Masselink (12), Wright (12), Bryant (11), Howitt (8), and Thoms (8). The network exhibits low isolation, with the largest cluster comprising 111 items. It is worth noting that Short, the most cited author, is isolated from the main core, likely due to his status as a renowned author in a specific area: coastal geomorphology (Figure 7).

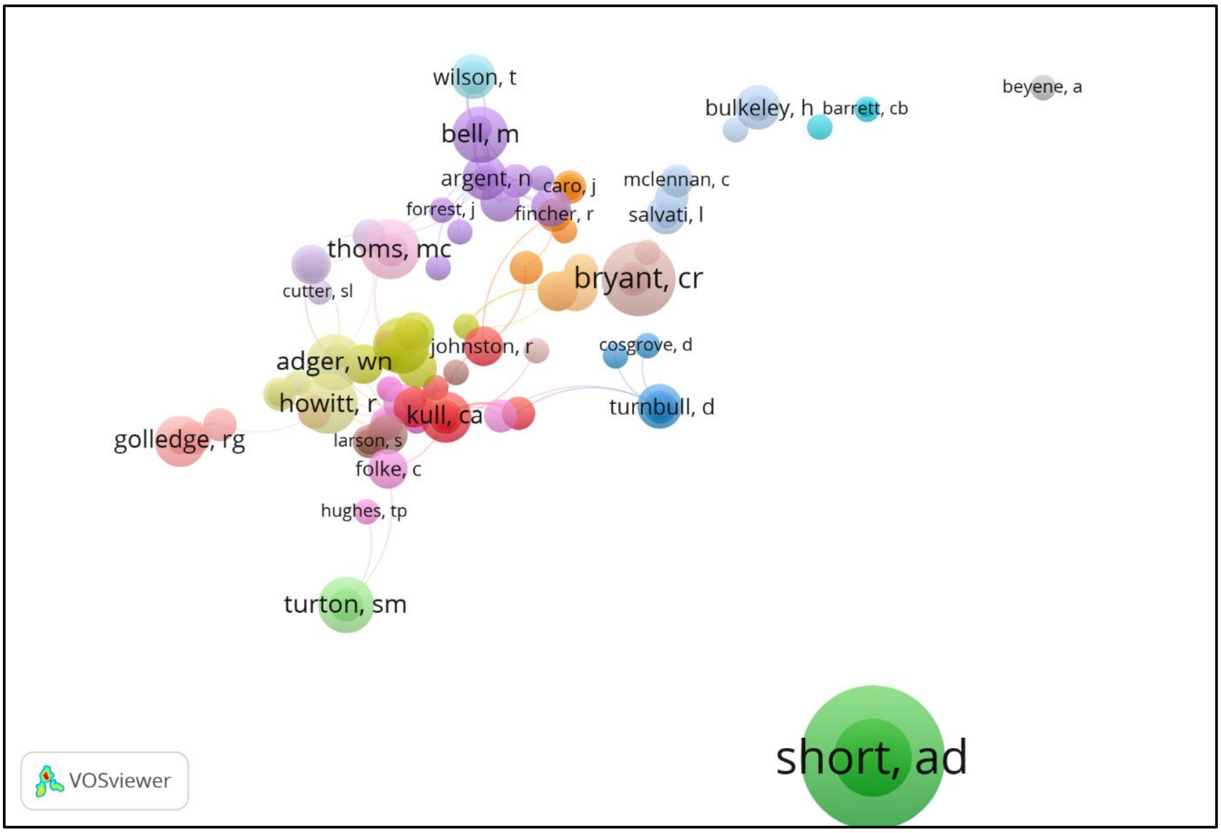

Figure 7. Co-citation of authors in *Geographical Research*. Note the presence of a diverse main core and the isolation of Short, the most co-cited author in the sample. Source: VOSViewer.

Finally, with regard to the affinity categorization of the ten most-cited articles from each of the 20 journals selected in the sample field, significant conceptual distancing was observed, with low-affinity predominating among Q1 journals and moderate affinity among Q2 journals. In terms of "low affinity," a methodologically defined classification category, the journals *Antipode* (ID #3, 8 occurrences), *Soil and Tillage Research* (ID #4, 7 occurrences), and *Palaeogeography, Palaeoclimatology, Palaeoecology* (ID #37, 7 occurrences) stood out. On the opposite end of the spectrum, in terms of occurrences of "high affinity," only the journal *Hydrological Processes* (ID #42, 6 occurrences) emerges. The thematic focus of these journals may explain their greater or lesser proximity to the referenced application of systemic approach concepts. However, this is a preliminary analysis that requires further investigation. The subjectivity of the analysis also needs to be considered, as it involves categories whose relativity results from the researchers' perception.

4. Discussion

Although some journals in the sample showed a certain temporal stagnation in the number of published documents, it was possible to observe a growing trend in publications in geomorphology influenced by the systems approach. However, it is essential to consider the limitations of the method, as the complete metadata indexing on the Web of Science, including abstracts, is established for works from the 1990s onward. Documents from before the 1990s were gradually added to the database but do not comprise the entirety of it.

Nevertheless, even considering the 1990s as a starting point, the sample continues to exhibit a growing trajectory, with occasional positive and negative peaks. The broader bibliometric research, which includes the topic "geomorphology" in the Web of Science database, showed the same pattern: an increase in the use of terms related to the systems approach starting in the 1990s, with intensification in the following decade.

The popularization of terms related to the systems approach in scientific publications since the 1990s and 2000s also aligns with the cultural zeitgeist ("spirit of the time"). During these decades, themes like the Butterfly Effect and Chaos became recurring in popular mass culture, with audiovisual productions (*Run Lola Run* in 1998; *Donnie Darko* in 2001; *The Butterfly Effect* in 2004). In science popularization literature, more closely linked to contemporary scientific avant-gardes, this phenomenon had already been observed earlier, with widely distributed books aimed at the general public in the decades of: 1970 (*The Limits to Growth* by Donella Meadows; *Le Hasard et la Nécessité* by Jacques Monod; *Gaia: a New Look at Life on Earth* by James Lovelock), 1980 (*Chaos: Making a New Science* by James Gleick – Pulitzer Prize in 1987), 1990 *(The Web of Life* by Fritjof Capra*; La Fin des Certitudes: Temps, Chaos et les Lois de la Nature* by Ilya Prigogine; *The Quark and the Jaguar* by Murray Gell-Man) e 2000 (*Introduction à la Pensée Complexe* by Edgar Morin; *Complexity: a Guided Tour* by Melanie Mitchell).

In terms of scientific recognition, it is worth emphasizing the recent awarding of the 2021 Nobel Prize in Physics to Giorgio Parisi, Syukuro Manabe, and Klaus Hasselmann for their research that provided a theoretical foundation for modeling Earth's complex systems: "*Planet Earth is a complex system, perhaps much more complex than we know, precisely because it encompasses everything within itself. The entire development of the world, ecological systems, is a complex system*" (FERRAZ, 2021).

Additionally, the temporal analysis tool for term usage in literature, Google Ngram, allows for a brief comparison with the results obtained through bibliometric analysis (Figure 8). It is possible to observe that the simple use of the term "systems" peaked in the mid-1980s, followed by a decline until an apparent recent stabilization. Interestingly, the growth rates between 1950 and 1980 are similar to the decline rates observed between 1980 and 2015. On a more detailed scale, focusing on the term "complexity," a different scenario emerges: growth until the mid-2000s, followed by apparent stabilization. Thus, even with different scales of use, the consolidation of ideas around complexity appears to have occurred later than those of systems, which aligns with the consulted bibliography.

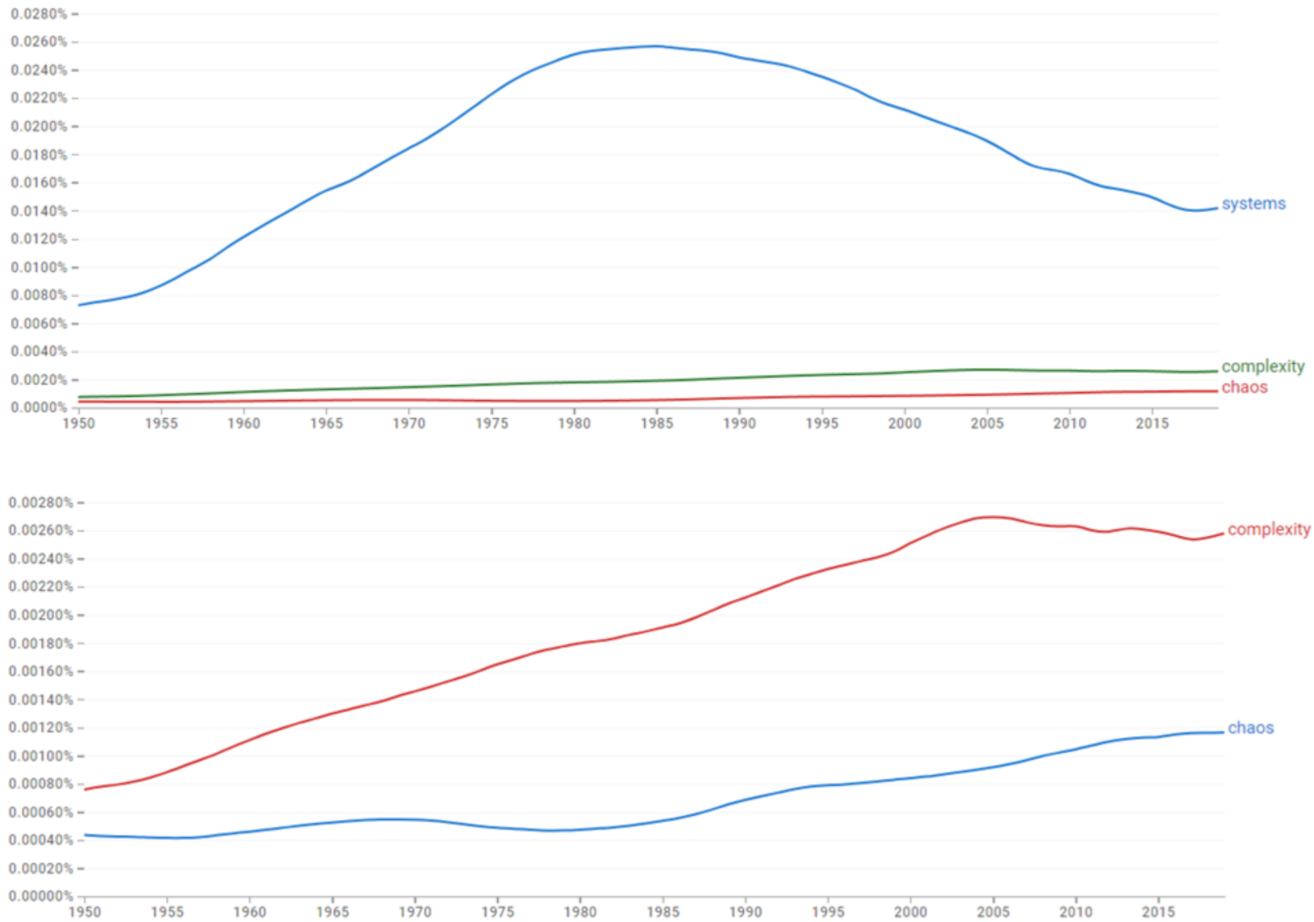

Figure 8. Usage of the terms "systems," "complexity," and "chaos" on Google Ngram from 1950 to 2019. Source: Google Ngram.

The bibliometric analyses for Q1 and Q2 showed similarities in terms of country of origin, which may indicate the coherence of the results and the configuration of a well-defined scenario in scientific production. The predominance of the English language and the geographical distance of the universities hosting the most productive journals still pose a barrier for emerging countries. These are countries far from the "geopolitical North" and often struggle with basic infrastructure and research funding issues. Perhaps only China stands out as a protagonist in challenging the status quo and the hegemony of the "geopolitical North," emerging as a global economic reference and registering notable strides in its scientific production in recent decades. A thorough analysis of this growth pattern may provide insights into the phenomenon, which already demonstrates China's prominence in terms of the number of scientific documents published in various fields, even though citation rates grow at a slower pace.

De Grijs (2015) recognizes the importance of collaboration among researchers from different nations, fostering the exchange of ideas, methodologies, and the consolidation of academic networks. The author outlines rules for the consolidation of international scientific collaborations — a domain that enables innovation but is also fraught with challenges such as cultural and language differences. Nevertheless, Wagner and Leydesdorff (2009) confirmed a phenomenon of inflated international collaboration in the 1990s and 2000s, with linear growth in the number of published documents and exponential growth in international correspondents. These global collaboration networks result in a core group that quantitatively dominates articles published in leading journals. In this regard, the authors identified that fourteen industrialized nations reinforced their prominence between 2000 and 2005, aligning with earlier interpretations of the predominance of "geopolitical North" publications in this study's sample. These countries possess strong national systems that maintain their privileged position in international scientific leadership, while peripheral countries are disadvantaged by the strength of this dominant group. Finally, the authors define science at the international level as a complex adaptive system whose order emerges from the interaction of hundreds of agents, each with unique strategies pursuing individual interests. This aspect is also evident in the present research but requires further exploration in future studies.

Concerning interdisciplinary and transdisciplinary influences on the origin of the systems approach, it is undeniable that its development in Geomorphology was the result of interdisciplinary influences. The very creation of General Systems Theory by Bertalanffy was influenced by fields such as Biology and Thermodynamics, including Geosciences. Although many students and young researchers first encounter the systems approach in Geomorphology through authors influential in the discipline, such as Sotchava, Tricart, and Bertrand, direct engagement with renowned figures like Ilya Prigogine (and his work on Thermodynamics) is not uncommon.

Over the decades, scientific trends have profoundly impacted methods both within and beyond Physical Geography, which experienced its Quantitative Revolution. Contemporary developments such as Norbert Wiener's Cybernetics and Claude Shannon's Information Theory in the 1940s, Henri Poincaré's Dynamic Systems in the 1950s, Edward Lorenz's Butterfly Effect (and consequent Chaos Theory) in the 1960s, and advances in computing power transformed landscape evolution models, making them increasingly present in the researchers' routines.

As Church (2010) states, if Systems Sciences seek explanations through the integration of various elements and processes, then Geomorphology is, essentially, a Systems Science. According to the author, the context of systems in Geomorphology is characterized by five general features: the juxtaposition of different physical processes in time and space, processes occurring at various temporal and spatial scales, the configuration of matter stocks (represented as sediments and morphology), the existence of thresholds and limits, and dynamics at all temporal scales. Therefore, the possible consolidation of Geomorphology as a Systems Science was pointed out by several authors, such as Chorley (1962), Chorley and Kennedy (1971), and Schumm (1973), but it would be with the computational leap that, in fact, these models became popular.

However, the interdisciplinary incorporation of principles from other disciplines is not a one-way street, nor does it progress in a linear fashion. There are bifurcations and obsolescence of literature along the way. The very history of Geomorphology has seen two major schools throughout its development. Abreu (2003) highlighted, for example, the more collectivist nature of the German school (with a larger number of equally prominent and mutually influential figures) compared to the Anglo-American school, which was marked by more centralized figures (a less branched trajectory). Thus, it would not be surprising if the incorporation of new concepts and methods itself reflected this diversity of approaches. Orme (2002) identified elements from other disciplines related to possible paradigm shifts in Geomorphology and Earth Sciences but made an important caveat: not all innovative ideas in the discipline were, in fact, incorporated into the researchers' broad methodological vocabulary over the decades. As the author delineates, science is replete with high-quality ideas and observations that were ignored or rejected by the scientific community, shaping not only the epistemological paths of a given science but also the degree of recognition afforded to its authors.

The very appropriation of concepts and methods varies within a single discipline, reflecting the plurality of perspectives; this is no different in Geomorphology. Various subfields of Geomorphology have developed their own concepts and methods, drawing on the shared framework but also on interdisciplinary references. Lewin (2022), for instance, presented some concepts widely disseminated in Fluvial Geomorphology. Generally, much of the conceptual framework developed in this subfield, especially regarding the analysis of systems and processes, originates outside the discipline. On the other hand, there are also concepts and approaches that have fallen into disuse and been devalued over time. This is, therefore, a complex process of communication, absorption, revision, dissemination, and abandonment in the use of concepts over time — a history of either adopting or rejecting concepts that is filtered even through the lens of human psychology to determine the progress or stagnation of a particular conceptual scope.

And, naturally, the reverse pathway exists. Despite the evident influence of concepts and methodologies from other sciences on the history of Geomorphology, the influence of Geomorphology's scientific advances on other disciplines cannot be denied. Summerfield (1991), for example, summarized some of these intellectual flows, emphasizing the bidirectional appropriation of concepts and methodologies. After all, as Davies (1972 *apud* Christofoletti, 1980) pointed out, the evolution of geomorphological and sister-science thought demonstrates that the most significant scientific advances are not necessarily related to factual knowledge (data acquisition) but rather to new forms of analysis.

New ideas, global scientific trends, relationships between researchers, hegemonic bibliographic references, and debates ultimately shape the future of a discipline. In this "self-organized chaos," a complex and dynamic system endowed with physical and social variables, the discipline takes its shape over the centuries. As Gregory and Lewin (2014, Box 1.1, p. 17) aptly put: "*it might be said that the discipline of geomorphology has remained attractively un-disciplined*"; and this can be an incredible merit, fostering the emergence of new scientific paradigms.

In this way, despite some graphs indicating signs of possible stability or decline in the use of terms related to the systems approach in recent times, the systems approach has been solidified as a working method in Geomorphology, either directly or indirectly. It is an approach that, when combined with computational modeling, will always be in a constant process of technical improvement, enabling the incorporation of a larger amount of raw data, variables, and dynamics. In other words, it brings increasingly higher levels of complexity to the analyzed systems while technical advancements propose new products and identify new processes, in a spiral of constant reinterpretation of the approach itself.

On the other hand, one issue deserves attention: the relative isolation of the discipline concerning the whole, particularly regarding researchers who also work with the systemic approach in other fields. Returning to Castellani's (2018) graph, it is possible to observe an intricate, diverse, and complex map of interactions that encompass the history of Complexity Sciences. Different lineages pass through authors already discussed here, such as Bertalanffy, Poincaré, Shannon, Lorenz, Meadows, Rapoport, Prigogine, Wiener, and Mitchell, but there is no space for authors from Geography in this intricate network of interactions. Despite Castellani's apparent focus on the historical evolution of complex systems modeling — currently working on social systems modeling at Durham University — we see authors from Geology (James Lovelock), Philosophy (Edgar Morin), Linguistics (Noam Chomsky), and Biology (Robert May) included in his representation, examples distant from his focus. This raises the rhetorical question: why do such renowned authors within Physical Geography still seem distant from other sciences? In this context, the long-dreamed dissolution of boundaries between scientific disciplines, as envisioned by Bertalanffy in his General Systems Theory, still seems utopian.

The systemic approach and the current ramifications of Complexity Sciences have sought grounding in classic scientific paradoxes to define their research problems, such as Laplace's Demon and the Butterfly Effect. This repertoire has been used to discuss the limits of Determinism, in conjunction with integrated advancements from different areas of science aimed at understanding Earth's processes through models. For this purpose, computational modeling becomes a recurring tool in translating theoretical models into a controlled environment for empirical experimentation, whether in modeling natural, social, or economic systems, as well as their integration. Not surprisingly, the field of complex systems modeling has gained prominence beyond disciplinary boundaries, as demonstrated by the work produced by the Santa Fe Institute, an independent institution comprising researchers from international institutions dedicated to research on complexity through applied mathematics and artificial intelligence. In a Brazilian context, the University of São Paulo (USP) offers a graduate program entirely dedicated to the topic: the Graduate Program in Complex Systems Modeling.

A similar trend can be observed in Geomorphology and Physical Geography, resulting from discussions developing within and outside the discipline, with methodological proposals being presented and tested both internationally and nationally. From the renowned interpretations of Geosystems proposed by Sotchava and Bertrand to the discussions fostered by the Binghamton Geomorphology Symposium, in at least two editions entirely dedicated to the topic (PHILIPS; RENWICK, 1992; MURRAY; FONSTAD, 2007; MURRAY et al., 2009; SAWYER et al., 2014), methodologies based on the systems approach have become common in scientific publications of the 20th and 21st centuries. This phenomenon has developed in synergy and mutual influence with changes in scientific production observed in Physical Geography and Geomorphology, particularly in the emergence and popularization of Quantitative Geography.

Finally, regarding the possible conceptual detachment listed in the working hypothesis, more documents with medium affinity were obtained, followed by low affinity, good affinity, and excellent affinity, respectively. Thus, the initial working hypothesis is confirmed, as there are more works with medium and low affinity than those with good and excellent affinity. The low affinity diagnosed may even reflect a potentially shorter lifespan of publications in Geomorphology, in addition to other aspects related to literature obsolescence. It could also reflect the broad presence of research with a methodological application bias, which often lacks extensive bibliographic review.

Among the journals with the most documents classified as low affinity are *Antipode*, *Soil and Tillage Research*, and *Palaeogeography, Palaeoclimatology, Palaeoecology*. These are journals that, although classified as Earth-Surface Processes in the SJR, are more distant from the scope of Physical Geography and Geomorphology. On the other hand, *Hydrological Processes* is among the journals with the most items classified as excellent and good affinity, demonstrating the affinity of fluvial studies with systems approach concepts.

This information may be useful to support discussions about which disciplines and subfields of Geosciences have most appropriated the key concepts and related methods of the systems approach, as each of these journals has defined scopes. Recent works, such as Gomes (2023), have used other methodologies to recognize the production patterns of the plural Brazilian Geography during the 20th century, including a protagonism of the systems approach in Physical Geography, for example.

However, it is essential to emphasize that the categorization presented in this research is of a qualitative-quantitative nature. The essence of document classification by affinity is subjective and passed through the researcher's perception within a specific time frame. The pursuit of new methods, less susceptible to such subjectivity, should be encouraged to deepen future discussions and improve the method.

5. Conclusions

The present research outlined a historical overview of the influence of the systemic approach on the production within Geosciences over recent decades, particularly in the field of Geomorphology. To achieve this, qualitative and quantitative analysis tools were employed, including literature review, bibliometric research of bibliographic metadata, and categorization of applied concepts.

The results indicated a general trend of increasing use of terms and concepts related to the systemic approach in Geomorphology, albeit at a slower pace compared to the peak of thematic popularity in the 1980s and 1990s. This global trend is not evenly distributed across continents, reflecting the unequal reality of international scientific production. However, a conceptual gap between the use of these terms and the theoretical framework of the systemic approach was observed and warrants further investigation.

In this context, concepts such as system, complexity, nonlinear systems, dynamic systems, open and closed systems, order/disorder, chaos, universality, equilibrium, self-organization, emergence, and resilience are among the most recurrent in research dedicated to the systemic approach. Regardless of the research line in which they are applied — whether in modeling fluvial systems, studying the evolution of coastal geomorphology, or urban and regional planning for disaster risk reduction — these concepts are adapted and transformed for different practical and academic applications.

Although still far from Bertalanffy's ideal of a unified science, a "Science of Systems," systems approaches have been part of the work of geomorphologists and geoscientists for decades. At times, the temporal distance and dispersion of these interdisciplinary (or transdisciplinary) ideas have led to conceptual detachment and a loss of reference links to the past. Nevertheless, their influence remains significant and continues to grow.

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