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Quantifying Neutrosophic Research: A Bibliometric Study

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Abstract: In recent years, neutrosophic theory has garnered increasing attention within scholarly circles due to its applicability in various domains. Within these domains, the field of decision-making has derived significant advantages from the progressions in neutrosophic theory. Notably, neutrosophic theory has made substantial contributions by advancing and offering a range of aggregation operators and information measures specifically designed for enhancing decision-making processes. In this context, this study aims to conduct a comprehensive bibliometric analysis of the current research landscape in the field of neutrosophic theory, with a specific focus on understanding its applications and development trends. Our analysis reveals that the scientific literature addresses neutrosophic theory in a diverse range of applications. This examination encompasses a scrutiny of key contributors, affiliated academic institutions, influential publications, and noteworthy journals within the neutrosophic domain. To achieve this, we have curated a dataset comprising scholarly papers retrieved from Clarivate Analytics' Web of Science Core Collection database, employing keywords closely aligned with neutrosophic theory and its applications, spanning a specified timeframe starting from the year in which the first paper on neutrosophic theory was published, namely, from 2005 until 2022. Our findings underscore sustained and robust scholarly interest in neutrosophic theory, characterized by a considerable high annual growth rate of 43.74% during the specified period. Additionally, our investigation delves into the identification and analysis of pivotal keywords and emerging trends, shedding light on prominent research trajectories within this domain. Furthermore, we elucidate collaborative networks among authors, their academic affiliations, and the global distribution across diverse countries and territories, providing valuable insights into the worldwide proliferation of neutrosophic research and applications. Employing n-gram analysis techniques across titles, keywords, abstracts, and keyword-plus fields unveils a multitude of applications where neutrosophic theory plays a central role. The analysis culminates in a review of globally cited documents and a comprehensive discussion highlighting the significance of neutrosophic theory in contemporary research and problem-solving contexts.

Keywords: neutrosophic; fuzzy measures; fuzzy logic; classical sets; bibliometric analysis

MSC: 03-XX; 03B52; 11Uxx

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1. Introduction

Neutrosophy was introduced as a novel philosophical discipline by Smarandache [1]. This framework is grounded in the fundamental premise that every conceptual notion inherently embodies a particular level of veracity, while concurrently exhibiting degrees of indeterminacy and falsity [2].

The novel dimension of indeterminacy within the emerging field of neutrosophy is comprehended through the lens of Smarandache [1] in a dual capacity, encompassing both subjective and objective perspectives. This encompasses not only the notion of uncertainty, but also imprecision [2].

According to Peng and Dai [3], neutrosophy is characterized as a multi-valued logical framework that incorporates classical and fuzzy logic, in addition to imprecise probability. Furthermore, the authors contend that neutrosophy achieves a closer alignment with human rationality. They substantiate this assertion by positing that neutrosophy offers a mechanism for discerning imprecision in knowledge and linguistic inaccuracies as articulated by multiple observers [3].

Given the diverse approaches encompassing both the theoretical foundations and practical applications within the field of neutrosophic theory, the present paper endeavors to furnish a comprehensive survey of studies published up to the conclusion of 2022 and cataloged within Clarivate Analytics' Web of Science Core Collection, formerly known and referred to as the Web of Science (WoS) database [4].

In order to assess the structure of the neutrosophic field and to observe its evolution, a bibliometric approach [5–7] was conducted, as this offers the needed means for properly identifying the topics and the impactful articles, authors, and journals within the neutrosophic field. Contrary to a review analysis, whose main scope is to provide a summary of the contents of a particular research field and a summary of the most important findings with regard to a particular field, a bibliometric analysis focuses more on the structure of a particular field, highlighting its development [8].

In this context, the aim of the paper is to provide an overview of the structure of the neutrosophic field and its development.

As secondary research objective, we aim to answer the following research questions:

- Which are the most impactful articles in the area of neutrosophic theory?
- Who are the most prominent authors based on the number of papers/number of citations in the area of neutrosophic theory?
- Which are the most chosen/impactful journals for papers in the area of neutrosophic theory?
- Which are the leading universities in the field of neutrosophic theory?
- How has the scientific production related to neutrosophic theory evolved over time?
- What are the characteristics of the collaboration network between authors in the area of neutrosophic theory?

Consequently, a collection of papers was extracted from the WoS database and subjected to a comprehensive bibliometric analysis. This analysis encompassed an examination of annual scientific output, the trajectory of citation counts, the identification of prominent authors and their affiliations, prominent countries of origin, and collaborative networks within the selected dataset. Furthermore, an n-gram analysis was employed to facilitate a more nuanced exploration of pivotal terms within abstracts, titles, author keywords, and keywords plus. Biblioshiny, developed by Aria and Cuccurullo [9], was selected for conducting such an analysis, following the approach used in similar studies in the field [10].

The remainder of this paper is structured as follows: Section 2 presents the steps followed for extracting the database of neutrosophic articles. Section 3 presents the results of the bibliometric analysis and highlights the most prominent articles, authors, countries, journals, and universities, along with an n-gram analysis of the most used words in titles, abstracts, keywords, and keywords plus. Section 4 is dedicated to discussions, while Section 5 provides the limitations of the study. The paper ends with concluding remarks.

2. Materials and Methods

The bibliometric analysis for determining the evolution of the field associated with neutrosophic theory was conducted in the manner suggested by similar works published in the field that have used the same methodological approach [11,12]. As a result, the analysis

was divided into two main parts: the first one dedicated to dataset extraction, and the second one focusing on the dataset analysis, as presented in Figure 1.

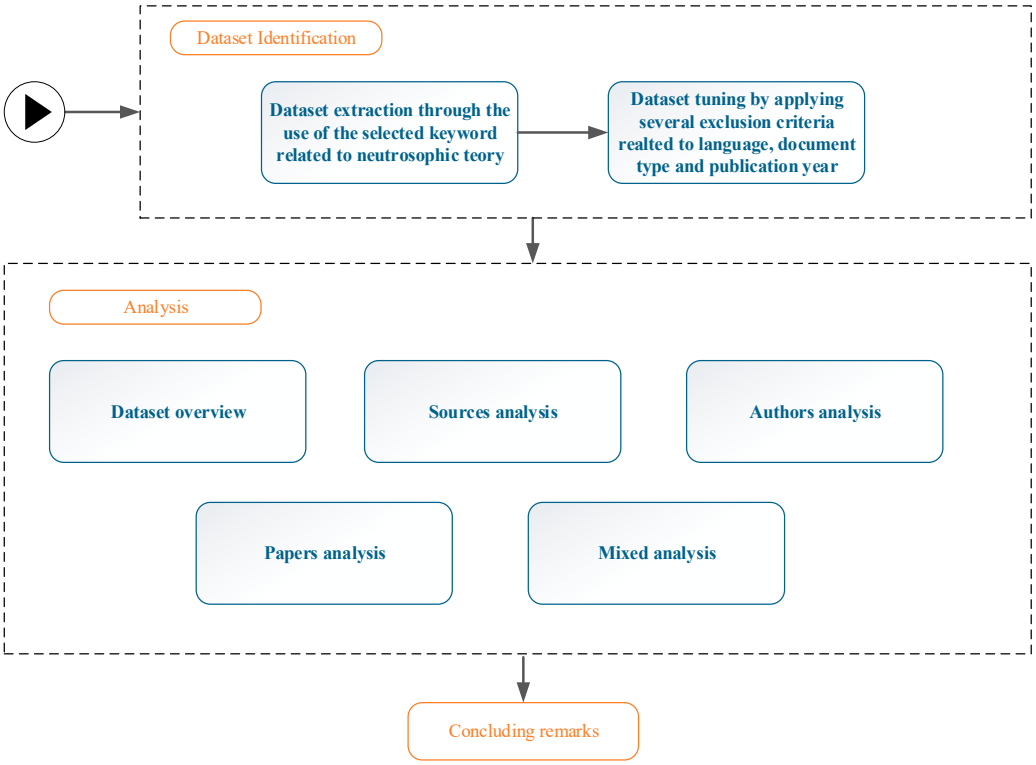

Figure 1. Bibliometric analysis steps.

While various databases can be employed for conducting bibliometric analyses, such as Scopus, IEEE, Google Scholar, PubMed, and Cochrane Library, this study exclusively extracted bibliometric data from Clarivate Analytics' Web of Science Core Collection database. The selection of this platform was underpinned by two primary rationales, as elucidated by Bakir et al. [13]: firstly, the extensive coverage of diverse disciplines and the inclusion of journals indexed therein, which are widely acknowledged as the most reputable within the scientific community [14,15]; and secondly, notwithstanding WoS's comparatively lesser inclusivity compared to its database counterparts, it stands as the preeminent database most frequently employed in scientific literature [16]. Furthermore, the files exported from the WoS database can be imported in the bibliometric analysis software that we used, namely, Biblioshiny [9]. It should be noted that some of the most well-known and used bibliometric analysis platforms, such as Biblioshiny and VOSviewer, have a limited data-reading capacity from bibliographic database files. For example, Biblioshiny works with WoS, Scopus, Dimensions, Lens, PubMed, and Cochrane Library [9], while VOSviewer works with files extracted from WoS, Scopus, Dimensions, Lens, and PubMed [17].

For the first part, represented by dataset extraction, we considered the analysis conducted by Peng and Dai [3] on Clarivate Analytics' Web of Science Core Collection database [4], and we used the keyword "neutrosophic" applied on the same database. Clarivate Analytics' Web of Science Core Collection comprises ten sub-datasets made up of eight citations indices and two chemical indices. The access to the database is personalized for each user based on the subscription type offered by the institutional access of each user. According to Liu [18], depending on the number of sub-datasets one has access to, the results of the search performed on the WoS platform can be different. In this context, as pointed out by Liu [18] and Liu [19], it is imperative for the papers dealing with bibliometric analyses to correctly define and provide the information related to the used sub-databases.

As a result, we have to mention that, in our case, the search was conducted considering the all ten indexes offered by WoS, as follows:

- Science Citation Index Expanded (SCIE)—1900–present;
- Social Sciences Citation Index (SSCI) 1975–present;
- Arts and Humanities Citation Index (A&HCI)—1975–present;
- Emerging Sources Citation Index (ESCI) 2005–present;
- Conference Proceedings Citation Index—Science (CPCI-S)—1990–present;
- Conference Proceedings Citation Index—Social Sciences and Humanities (CPCI-SSH) —1990–present;
- Book Citation Index—Science (BKCI-S)—2010–present;
- Book Citation Index—Social Sciences and Humanities (BKCI-SSH)—2010–present;
- Current Chemical Reactions (CCR-Expanded)—2010–present;
- Index Chemicus (IC)—2010–present;

A series of filters were applied for the database selection, as highlighted in Table 1. First, a search for the titles containing the word "neutrosophic" was performed, which revealed 2194 papers. In the second step, abstracts were filtered, looking for the word "neutrosophic", which returned 2472 articles. In the third step, keywords were searched for the word "neutrosophic", returning 2040 documents. In the fourth step, the filter was applied to find the papers that contained the keyword "neutrosophic" in their title, abstract, and/or keywords by applying a logic OR between the first 3 steps. As a result, a total of 2574 papers were extracted. Additionally, a series of exclusion criteria were applied, limiting the papers to those written in English, reducing the sample size to 2566 papers. Furthermore, we limited the papers to those marked as "articles" in WoS; this option further reduced the dataset to 2320 papers. Regarding the year of publication, the papers written in 2023 were not taken into account, as the year 2023 had not completely finished at the time when the search was performed. Keeping only a part of the papers published in 2023 (i.e., the ones indexed in WoS at the time of dataset extraction) for the analysis would have affected various indicators further discussed in this paper, such as the annual growth rate. Furthermore, we should state that the issue related to the inclusion/exclusion of some publication years from the analysis when the WoS database is considered has been previously discussed by Liu [20]. Please consider the work of Liu [20] for a comprehensive discussion related to the online publication date versus the final publication dates for the papers included in the WoS database. As a result, in the last step, the year 2023 was excluded, keeping papers until 2022, leaving a total of 2019 articles to be analyzed. A detailed presentation of each step is shown in Table 1.

Table 1. Data selection steps.

Exploration Steps	Search Fields/ Filters	Description	Query	Query Number	Count
1	Title	Contains neutrosophic-specific keyword	TI = (neutrosophic)	#1	2194
2	Abstract	Contains neutrosophic-specific keyword	AB = (neutrosophic)	#2	2472
3	Keywords	Contains neutrosophic-specific keyword	AK = (neutrosophic)	#3	2040
4	Title/abstract/keywords	Contains one of the neutrosophic-specific keywords	#1 OR #2 OR #3	#4	2574
5	Language	Limit to English	(#4) AND LA = (English)	#5	2566
6	Document type	Limit to article	(#5) AND DT = (article)	#6	2320
7	Publication year	Limit to 2022	(#6) NOT PY = (2023)	#7	2019

As for the second part, related to dataset analysis, several works from the field of bibliometrics [21–26] were considered and, as a result, the analysis was divided into six main steps: dataset overview, source analysis, author analysis, paper analysis, word analysis, and a mixed analysis.

The dataset overview step encompasses a discussion of various general metrics calculated for the dataset. These metrics include annual scientific production, the average number of years from publication, the average citations per document, average citations per year per document, and specific indicators relevant to selected documents, authors, or the collaboration network. These specific indicators encompass the count of keywords, the number of authors, the authors per document ratio, and the collaboration index.

The source analysis delves into an examination of the journals in which neutrosophic papers have been published, with an emphasis on highlighting the most prominent journals in terms of the number of publications, citations (H-index), and growth trends.

The author analysis focuses on the identification of notable authors, considering factors such as the number of published documents, total citations, productivity over time, affiliations, and countries of origin. Additionally, the country collaboration map complements the author analysis by providing insights into collaborative relationships between different countries.

The paper analysis centers on a detailed exploration of the top 10 most cited documents, including metrics such as total citations and total citations per year. Particular emphasis is placed on the contents of these papers, offering a comprehensive review and summary of their key elements, utilized data, and research objectives. Word analysis yields insights pertaining to the frequently employed terminology found in titles, abstracts, keywords, or keyword combinations. This analysis facilitates a more profound comprehension of the interconnected domains within the context of neutrosophic utilization. To achieve this objective, an n-gram analysis is executed, and the ensuing unigrams, bigrams, and trigrams are presented and subjected to critical discussion.

Finally, a comprehensive mixed analysis, rooted in a three-dimensional field plot, illuminates the intricate interrelationships among authors, their institutional affiliations, their geographic origins, keywords, and sources.

The elements included in each type of analysis are provided in Table 2.

Table 2. Main elements discussed in each type of analysis.

Analysis	Elements Included
Dataset overview	Timespan Sources Documents Average years from publication Average citations per document Average citations per year per document References Annual scientific production evolution Annual average article citations per year evolution Keywords plus Author's keywords Authors Author appearances Authors of single-author documents Authors of multi-author documents Single-author documents Documents per author Authors per document Co-authors per document Collaboration index
Source analysis	Most relevant journals Bradford's law on source clustering Journals' impact based on H-index Journals' growth (cumulative) based on the number of papers

Table 2. *Cont.*

Analysis	Elements Included
Author analysis	Top authors based on number of documents Top authors' production over time Most relevant affiliations Most relevant corresponding author's country Scientific production based on country Top countries with the most citations Country collaboration map Top 50 authors' collaboration network
Paper analysis	Top 10 most cited global documents—overview Top 10 most cited global documents—review Top 10 most frequent words in keywords plus Top 10 most frequent words in authors' keywords Top 50 words based on keywords plus and authors' keywords Top 10 most frequent bigrams in abstracts and titles Top 10 most frequent trigrams in abstracts and titles
Mixed analysis	Three-field plots

As for the program to provide the graphics and the data needed for the bibliometric analysis, we used Biblioshiny [9]. For this purpose, the Bibliometrix package was loaded in the RStudio console window through the use of the *biblioshiny( )* command. The choice of this approach is in line with other studies in the field that have used Biblioshiny [27–29].

3. Dataset Analysis

This section is devoted to the analysis of the extracted dataset of neutrosophic papers. As shown in the previous section, the data examined pertain to the works within the field of neutrosophy. The aim is to determine the foremost authors, assess the individual impact of their contributions, identify the predominant sources, and quantify the citations received by each article.

3.1. Dataset Overview

Distinct statistical analyses were generated for Tables 3–6, each offering unique insights into the data from diverse perspectives.

Table 3 provides an overview of key data characteristics. The data span from 2005 to 2022, encompassing 370 distinct sources and a total of 2019 documents. Notably, the average time elapsed since publication stands at 3.55 years, with an average of 18.44 citations per document. In total, 34,322 references are present, yielding an average of 3.513 citations per document per year. This reveals the emergence of a nascent domain, recently discovered, with a relatively limited number of publications. Many of these papers have been released in the past few years and have garnered significant numbers of citations, indicative of a rising interest in this field. The annual publication rate averages at 112 papers, drawing from 20.55 sources per year.

Table 3. Main information about the data.

Indicator	Value
Timespan	2005:2022
Sources	370
Documents	2019
Average years from publication	3.55
Average citations per document	18.44
Average citations per year per document	3.513
References	34,322

Figure 2 illustrates the annual scientific production for neutrosophic papers. During the initial years of the analyzed period, no articles on this subject were published. Commencing in 2014, the neutrosophic domain began to feature in the scientific literature. Subsequently, there has been a consistently positive trend, reaching its zenith in 2019, with 442 articles. The peak observed in the data extracted for 2019 may be the result of two phenomena: the increase trend noted for the previous period, which continued in 2019, and the occurrence of the COVID-19 pandemic, which led to an increase in the number of published papers. As Liu [19] pointed out, an abnormal increase in the number of research outputs is a rare case and can have a cause related to either a notable phenomenon of a given period or a problem in the data source. Given the increasing trend observed for the 2015–2018 period, along with the occurrence of the COVID-19 pandemic, which boosted the scientific production in all research fields, we think that the peak noted for 2019 is not an abnormal one, being the result of the two aforementioned causes. Notably, in 2021 and 2022, a stabilization in the number of published papers at around 300 articles was observed. The annual growth rate was calculated at 43.74%.

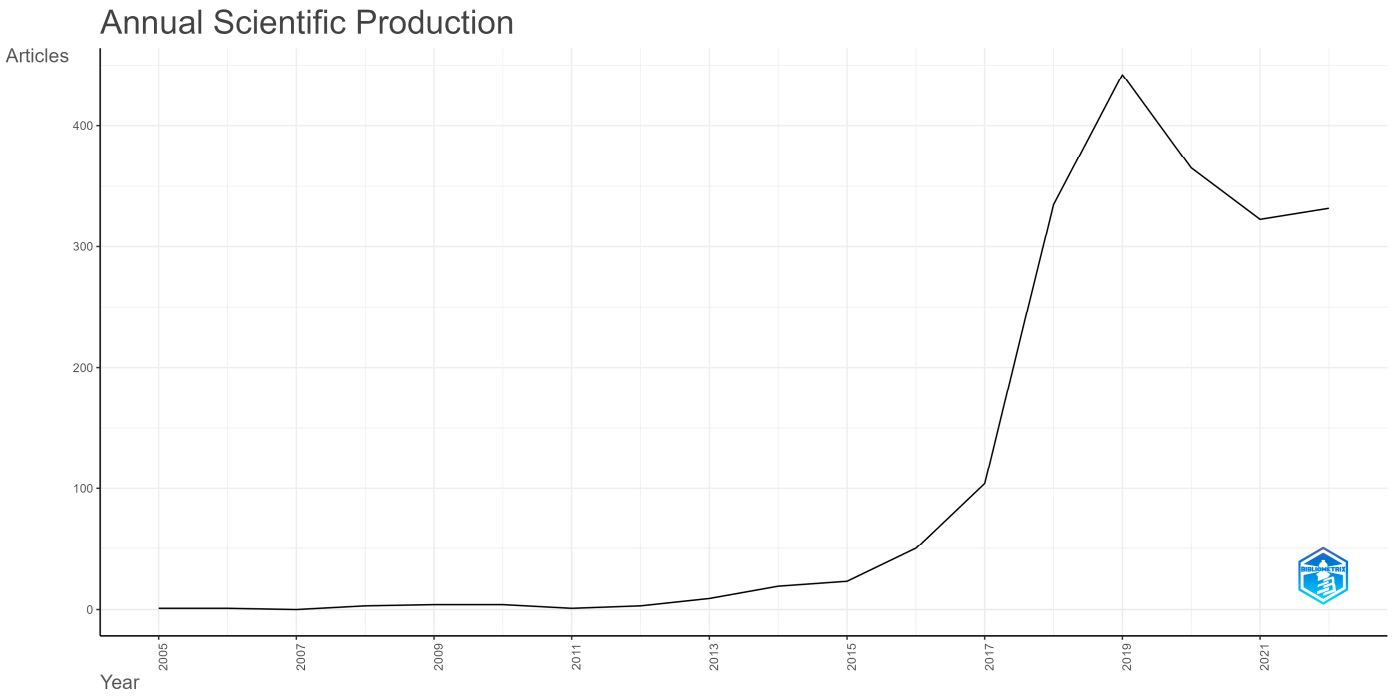

Figure 2. Annual scientific production evolution.

Figure 3 provides an overview of authorship trends from 2005 to 2022. Notably, Smarandache F. emerges as the most prominent author, making an inaugural contribution in 2016.

Subsequently, there was a substantial increase in publications, with peak outputs of 72 papers in 2018 and 89 articles in 2019. Aslam M. exhibited notable activity, with 36 papers in 2021, accompanied by a total annual citation count of 72.33. In 2018, Ye J. contributed 23 articles, with an average of 61.67 citations per year. Of special significance is Abdel-Basset M., who produced 17 papers in 2019, with an impressive average of 226.6 citations per year, indicative of high-quality scholarship. Wang J.Q. authored 19 articles in 2018, garnering an average of 155 citations per year. The comprehensive list of author production is available in Figure 3.

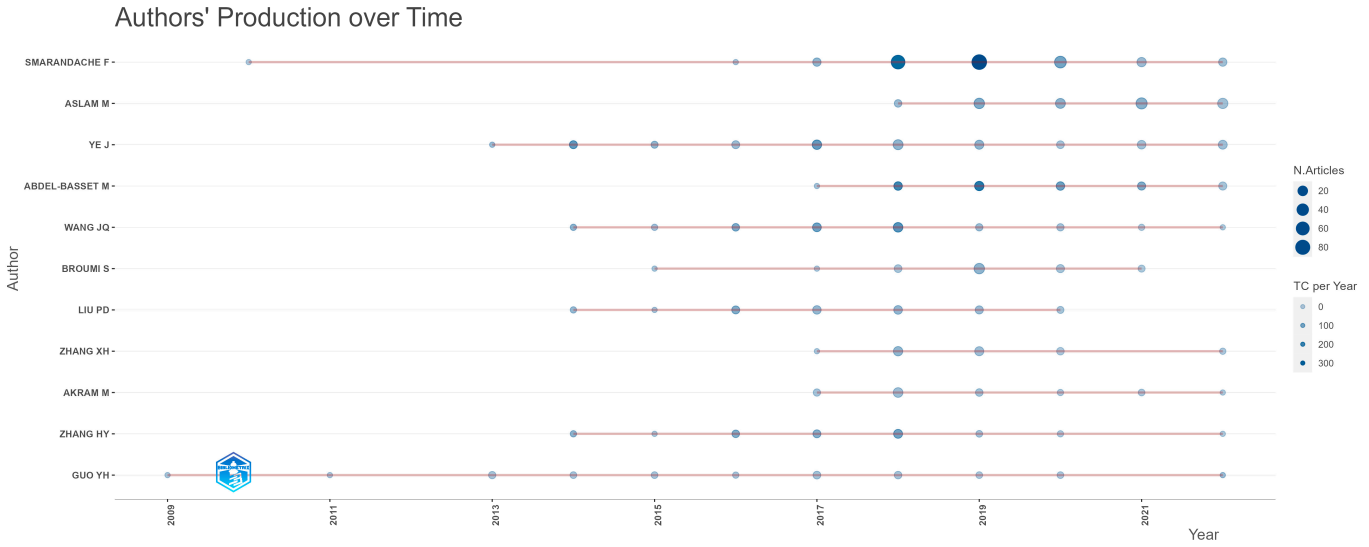

Figure 3. Annual average article citations per year evolution.

Table 4 provides an overview of document-related information. Keywords plus, generated automatically from the document titles, amounted to a total of 1432, equating to an average of 0.7 keywords plus per document—indicative of a relatively modest number. In contrast, authors' keywords assumed greater significance, with a total count of 5204, averaging 2.58 author keywords per document—a substantially more representative figure. As the values obtained for the keywords plus and for the authors' keywords were considerably smaller than expected, we further investigated the dataset and observed that, for 169 papers, no keywords were extracted. At first, we thought that the problem might be connected to the situation highlighted by Liu [30] related to the lack of these data for the papers published long before our time. Further investigating, we observed that the data were mostly missing for some recently published papers (e.g., 34 papers from 2020, 53 papers from 2021, and 44 papers from 2022), and only partially for the papers published at the beginning of the considered period (e.g., one paper from 2005, one paper from 2006). In terms of journals, there was a wide range of journals for which this situation occurred, such as *PLOS One*, *Complexity*, *Scientific Reports*, *Mathematical Problems in Engineering*, *Journal of Mathematics*, etc. As a result, after eliminating the 169 papers with no keywords, the updated value for the authors' keywords per document was 2.81, while the updated keywords-plus value was 0.77.

Table 4. Documents' contents.

Indicator	Value
Keywords plus	1432
Author's keywords	5204

Table 5 provides an overview of the author-related data. In total, there are 2663 authors who have contributed articles within the neutrosophic domain, resulting in an average of 1.32 authors per document. The number of single-author documents is notably low, comprising only 83 cases, underscoring the intricate and collaborative nature of this domain, with the majority (2580) involving multiple authors.

Table 6 provides insights into author collaboration within the neutrosophic domain. Of the total 2019 papers, a relatively small proportion (207 papers) are single-author. Another metric provided in Table 6 is the co-authors per documents index, which is determined as the average number of co-authors per article [31]. Notably, the average number of co-authors per document stands at 3.18, reflecting the expected high level of collaboration within this relatively new and complex domain. Additionally, the documents per author indicator

yields a modest value of 0.758, signifying that, on average, the majority of authors have contributed no more than one paper within this field. The authors per document indicator takes a value of 1.32. According to Aria and Cuccurullo [31], the authors per document index is determined as the ratio between the total number of authors and the total number of articles. As a result, even if an author has published more than one article, it is counted only once when determining this index. Comparing the value of the authors per document index with the co-authors per document index, one can think that the relatively small value for the authors per document indicator might be due to the fact that there are a lot of authors who have published multiple papers in the area of neutrosophic theory (these authors, due to the formula used for the authors per document index, were counted only once, even though they have authored multiple papers). Furthermore, the collaboration index, calculated by dividing the total number of authors of multi-author papers (2580 authors) by the total number of multi-author articles (1812 articles), stands at 1.42.

Table 5. Authors.

Indicator	Value
Authors	2663
Author appearances	6428
Authors of single-author documents	83
Authors of multi-author documents	2580

Table 6. Authors' collaboration.

Indicator	Value
Single-author documents	207
Documents per author	0.758
Authors per document	1.32
Co-authors per document	3.18
Collaboration index	1.42

3.2. Sources

The significance of sources holds considerable relevance, offering substantial insights into the landscape of journals, their prominence and impact, and the evolving publication trends over time.

Figure 4 provides a detailed account of the top 11 most influential journals within the neutrosophic domain. Leading the list is *Neutrosophic Sets and Systems*, which boasts an impressive 287 published documents. Following closely is *Symmetry-Basel*, with 181 documents, succeeded by *Journal of Intelligent & Fuzzy Systems* with 165 articles. *IEEE Access* and *Soft Computing* share the fourth position, each featuring 61 papers. *Mathematics* claims 59 documents, while *International Journal of Fuzzy Systems* and *Neural Computing & Applications* each have 37 articles. In the bottom three positions, *Applied Soft Computing*, *Journal of Mathematics*, and *Mathematical Problems in Engineering* contribute with 32, 31, and 30 papers, respectively.

Figure 5 showcases Bradford's law, a visualization that delineates the most cited journals within the neutrosophic domain, effectively demarcating them from other journals that have had a relatively minor impact. Bradford's law sorts the extracted journals into three categories based on the number of published papers [32,33]. If the proportion of the articles in each category is one-third of all articles, then the number of journals in each group would be proportional with $1{:}n{:}n^2$ [32,33]. Notably, the analysis revealed only four journals of notable importance, namely, *Neutrosophic Sets and Systems*, *Symmetry-Basel*, *Journal of Intelligent & Fuzzy Systems*, and *IEEE Access*.

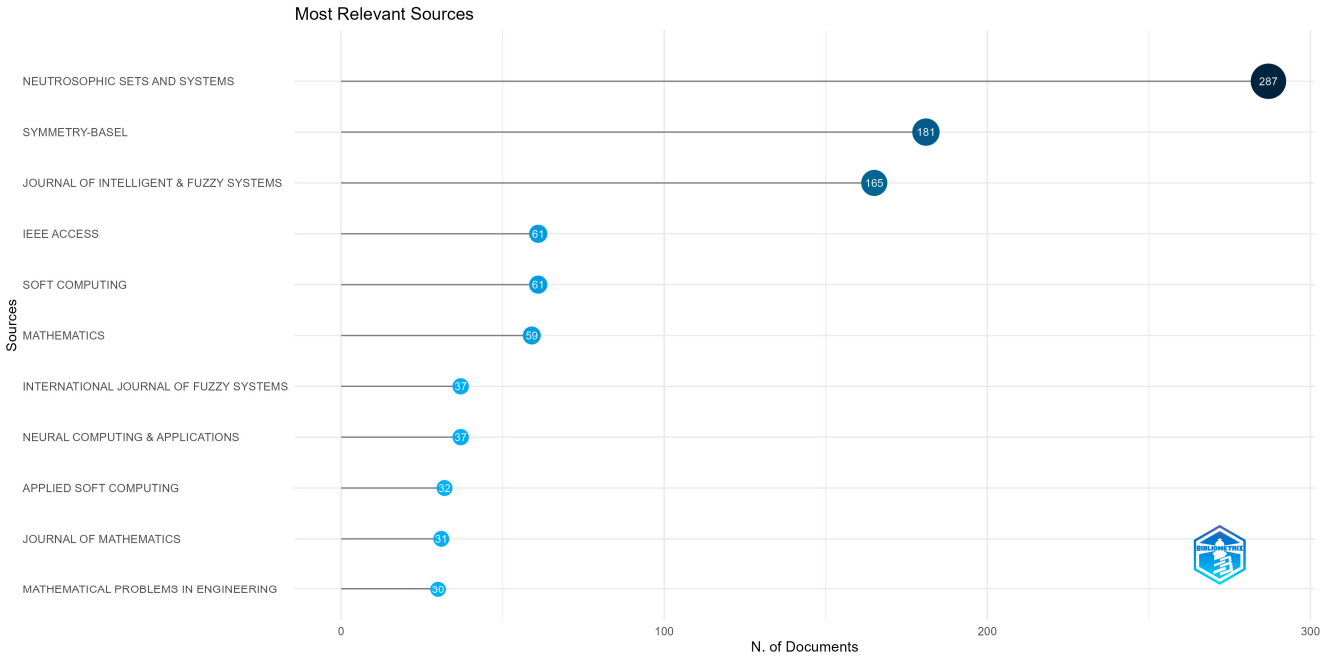

Figure 4. Top 11 most relevant journals.

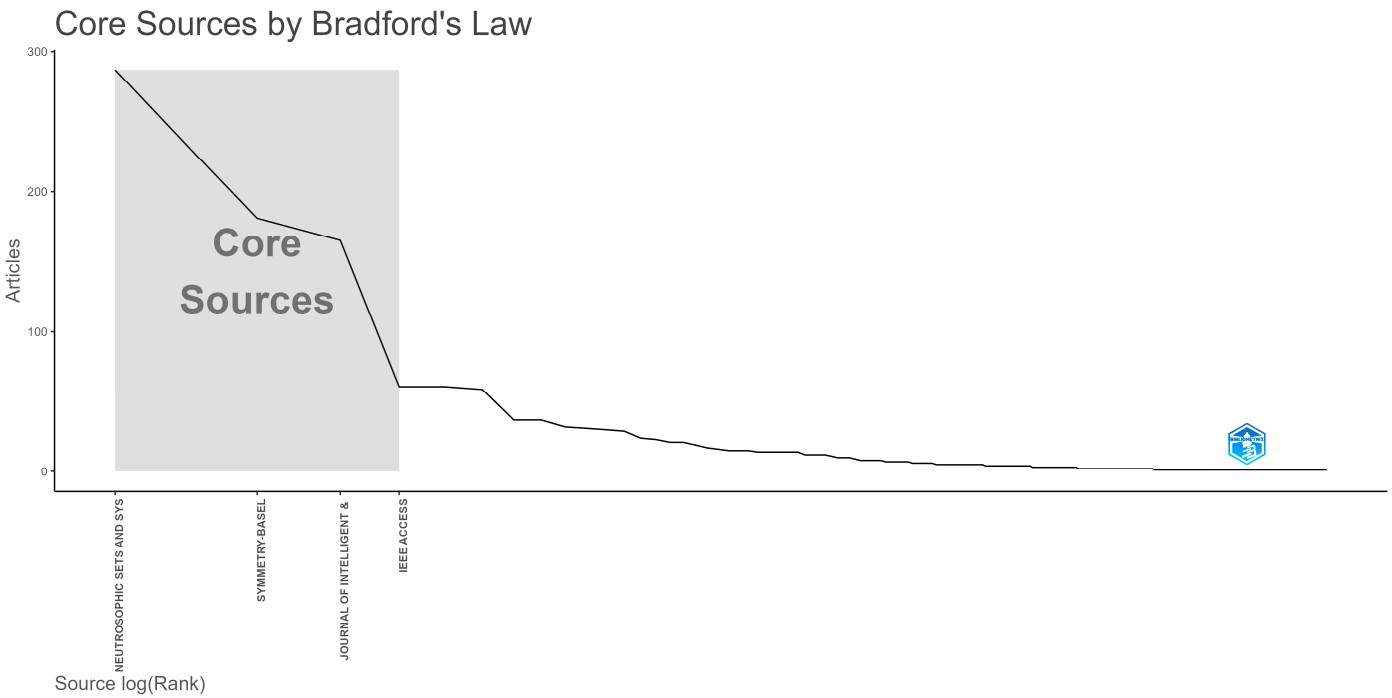

Figure 5. Bradford's law on source clustering.

Figure 6 provides a visual representation of journals with an H-index exceeding 12. The H-index serves as an indicator of a journal's significance, predicated on the interplay of its publication volume and citations. Notably, the most preeminent journal is *Journal of Intelligent & Fuzzy Systems*, boasting an H-index of 34, followed closely by *Symmetry-Basel* with an H-index of 30. *Neural Computing & Applications* holds an H-index of 28, while *Applied Soft Computing & Applications* has an H-index of 26. In contrast, the remaining journals exhibit H-indices ranging from 12 to 21—a considerably lower standing compared to the top three.

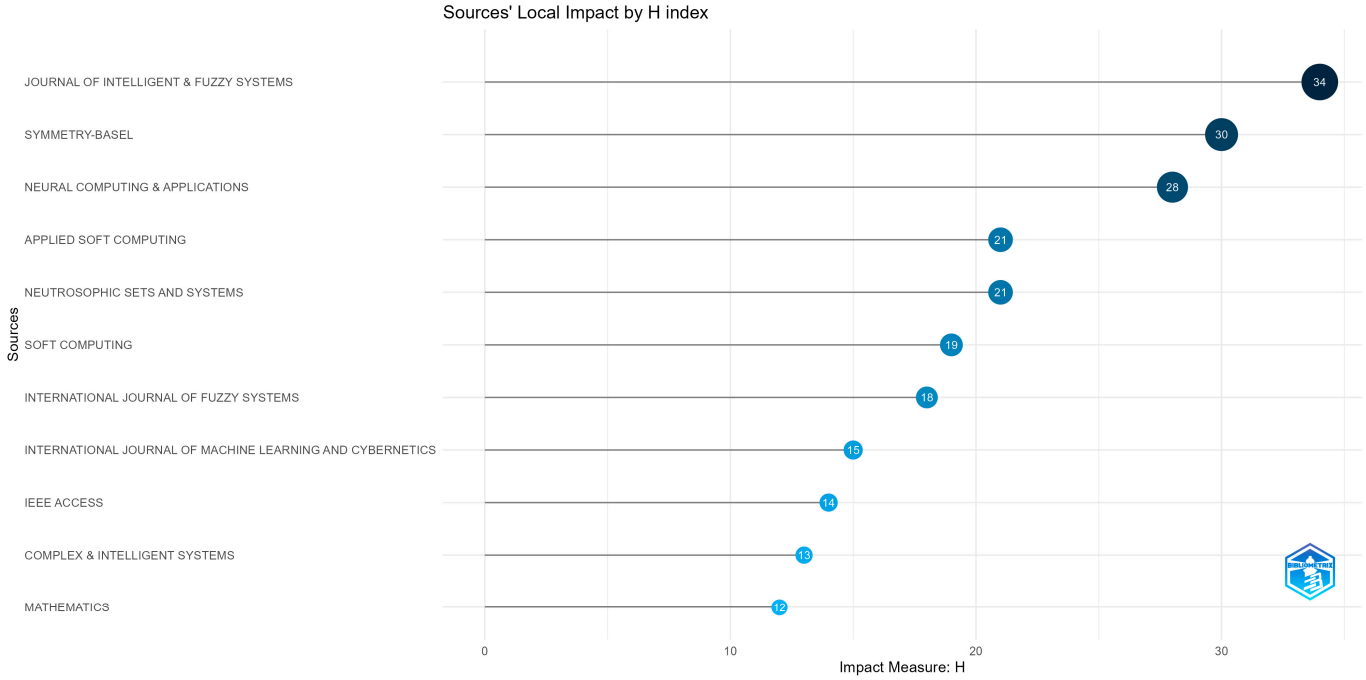

Figure 6. Journals' impact based on H-index.

Figure 7 provides a comprehensive view of the top five preeminent sources in the realm of neutrosophy, offering insights into the number of papers published over the course of the study period. Notably, *Neutrosophic Sets and Systems* secures the leading position in terms of paper output. *IEEE Access*, which ranks fourth in terms of the number of published documents, embarked on its journey in this domain in 2018.

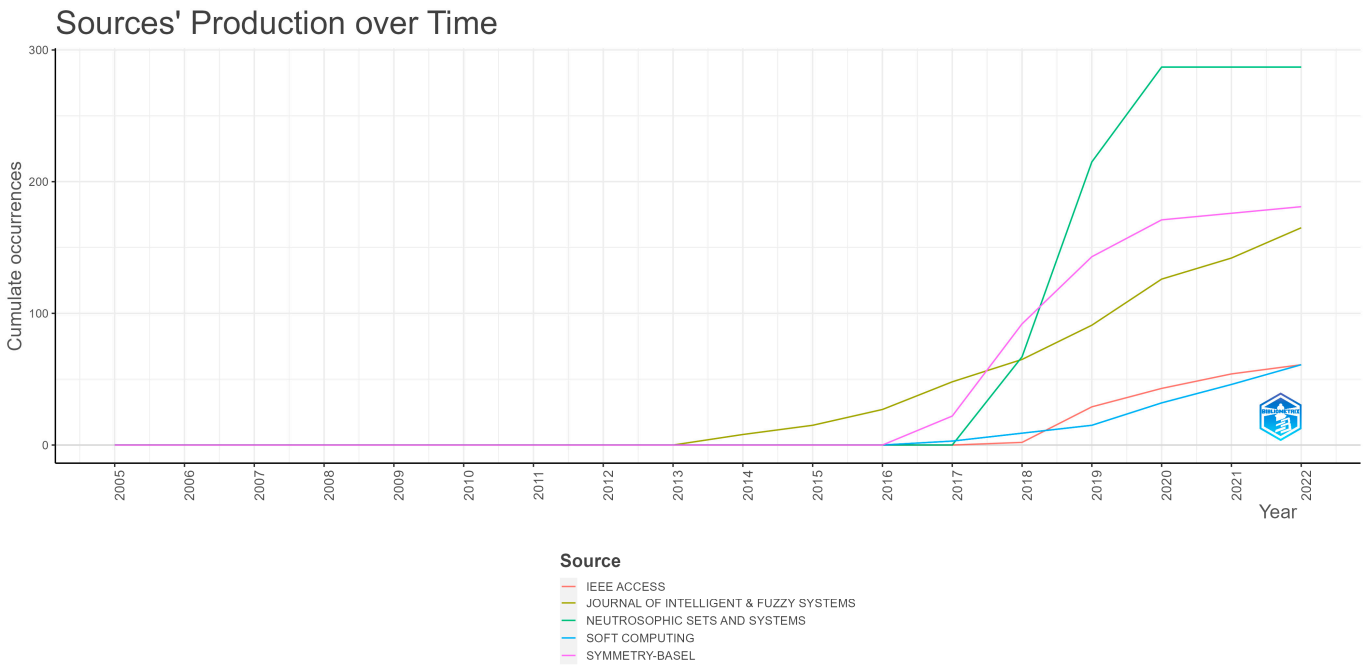

Figure 7. Journals' growth (cumulative) based on the number of papers.

In the case of the remaining journals, *Journal of Intelligent & Fuzzy Systems* commenced its exploration of neutrosophy in 2014, while *Symmetry-Basel* and *Soft Computing* initiated their engagement in 2017.

3.3. Authors

Authors play a pivotal role in bibliometric analysis, allowing for the identification of specialists within specific domains, as determined by factors such as the number of articles, citations, and sources.

The author with the most extensive body of work in the neutrosophic domain is Smarandache F., who has contributed a substantial 243 articles, followed by Aslam M. with 118 and Ye J. with 110 papers.

Abdel-Basset M. has published 58 articles on neutrosophy, Wang J.Q. has 55 articles, Broumi S. has 50 papers, and Liu P.D. has authored 47 documents.

Beyond this top group, the subsequent authors, extending to the eleventh position, have contributed fewer papers and exhibit comparatively lower relevance to the neutrosophic domain. The comprehensive list of authors can be found in Figure 8.

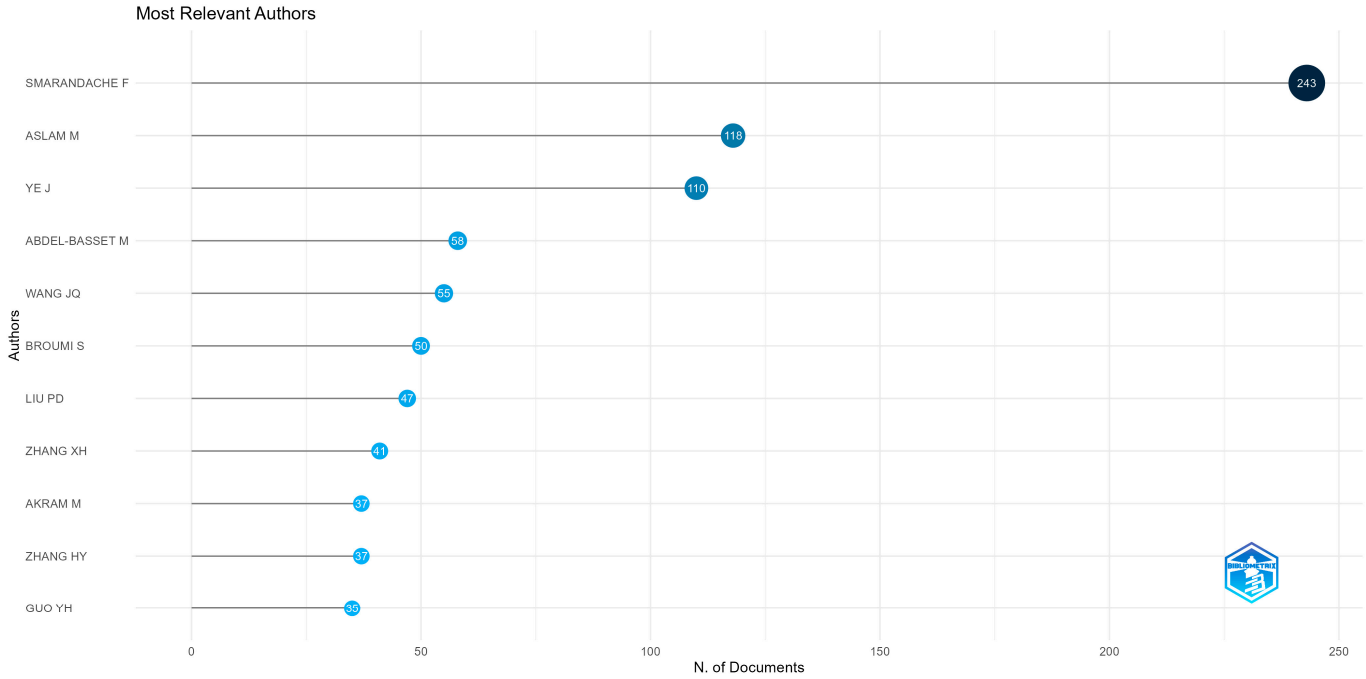

Figure 8. Top 11 authors based on number of documents.

Figure 9 illustrates how authors have contributed articles from 2005 to 2022. The most prominent author, Smarandache F., made his inaugural contribution in 2016, subsequently producing a substantial number of papers—notably, 72 in 2018 and 89 in 2019. Aslam M. presented 36 papers in 2021, with an impressive average annual citation rate of 72.33. In 2018, Ye J. authored 23 articles, garnering an average of 61.67 citations per year. Abdel-Basset M., in 2019, contributed 17 papers, with an exceptional average citation rate of 226.6, indicative of high-quality analysis. Wang J.Q., in 2018, presented 19 articles, with an average citation rate of 155 per year. A comprehensive listing of author contributions per year can be found in Figure 9.

Figure 10 provides a comprehensive summary of the numbers of articles published by various universities within the field of neutrosophy. Leading the list is "The University of New Mexico", with an impressive tally of 227 articles. In second place is "King Abdulaziz University", with 138 papers, closely followed by "Shaoxing University" with 126 articles. The fourth and fifth positions are occupied by "University of Punjab" and "Zagazig University", each having contributed 76 papers. "Vilnius Gediminas Technology University" rounds out the top universities, with 59 papers. Other universities, listed in full in Figure 10, have published fewer than 56 scientific papers.

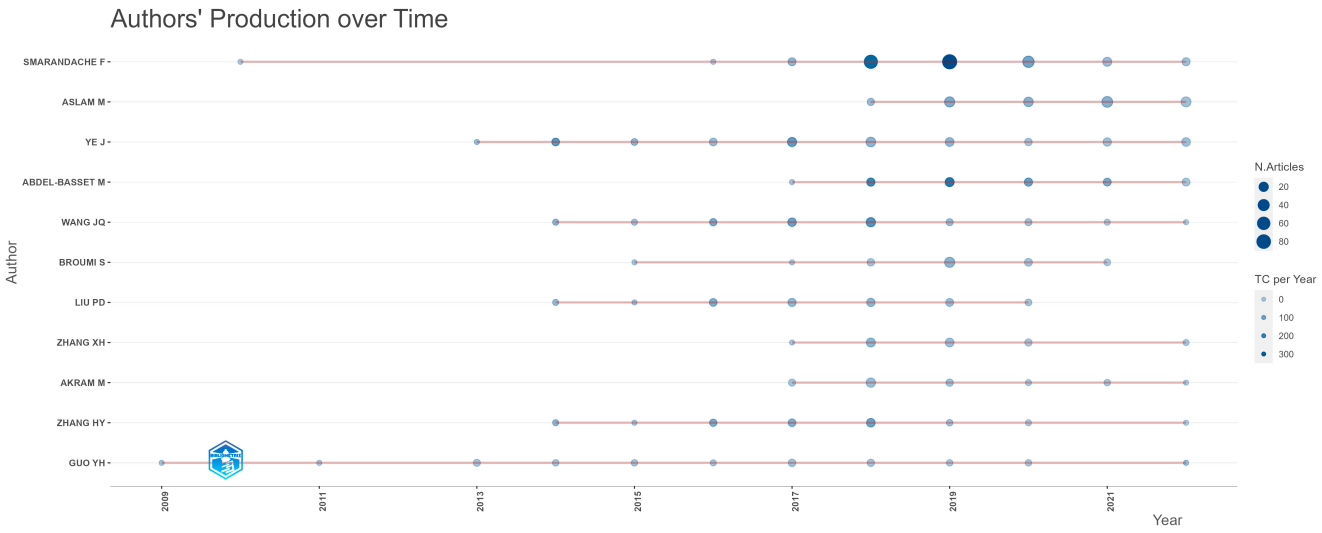

Figure 9. Top 11 authors' production over time.

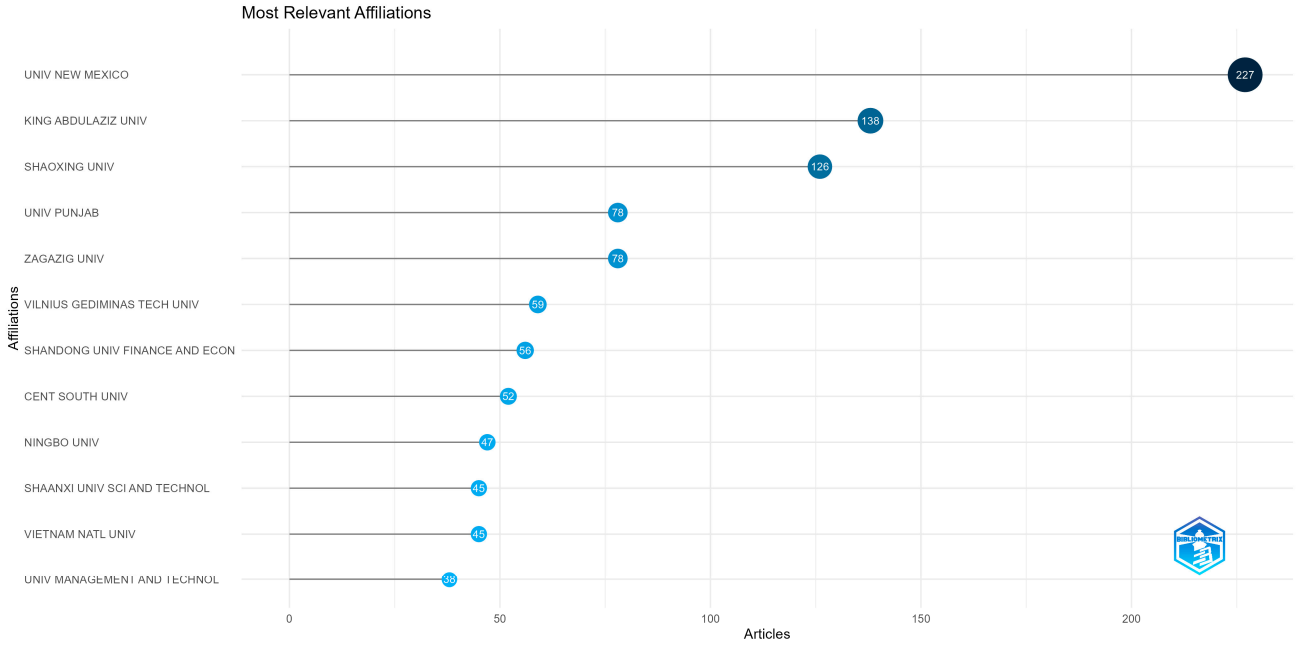

Figure 10. Top 12 most relevant affiliations.

Figure 11 offers a comprehensive overview of the corresponding authors' countries in the context of neutrosophic publications. The preeminent country in terms of the number of articles published in the neutrosophic domain is China, contributing 565 articles. Notably, 466 of these represent single-country publications (SCPs), where the authors were exclusively from China, while 109 articles fall under multiple-country publications (MCPs), involving authors from more than one country. China accounts for a substantial 28% of the total papers, underscoring a substantial interest among Chinese authors.

India occupies the second position, with 399 articles, comprising 288 SCPs and 111 MCPs, resulting in a frequency of 19.8%. Turkey follows as the third most prolific country, having published 185 papers, including 149 SCPs and 35 MCPs, with a frequency of 9.2%. Saudi Arabia stands as the fourth country, with 145 published documents, consisting of 74 SCPs and 71 MCPs, equating to a frequency of 7.2%. Pakistan ranks fifth, with 132 published papers, composed of 43 SCPs and 89 MCPs, accounting for 6.5% of the total.

Egypt has contributed 98 papers, with 42 SCPs and 54 MCPs, representing 4.8% of the total. Ecuador and the United States share the same number of papers, each having

54 publications, with 49 SCPs and 5 MCPs. Malaysia adds 49 papers to the list, featuring 22 SCPs and 27 MCPs, constituting 2.4% of the total. Iran rounds out the top 10, with 43 articles, encompassing 17 SCPs and 26 MCPs, and a frequency of 2.1%. The information is visually represented in Figure 11 for ease of reference.

Figure 12 provides a country-level presentation, offering insights into the numbers of articles published. The color scheme utilized in Figure 12 is based on the number of published papers, with darker colors denoting a higher quantity of articles. The country with the highest number of articles published in this domain is China, boasting 1140 publications, closely followed by India with 794 articles. Pakistan secures the third position, with 397 papers, while Turkey ranks fourth with 373, and the United States holds the fifth position with 344 articles. Saudi Arabia contributes 271 articles, Egypt adds 223, Vietnam features 138, Iran has 122, and Malaysia rounds out the top 10 with 98 articles.

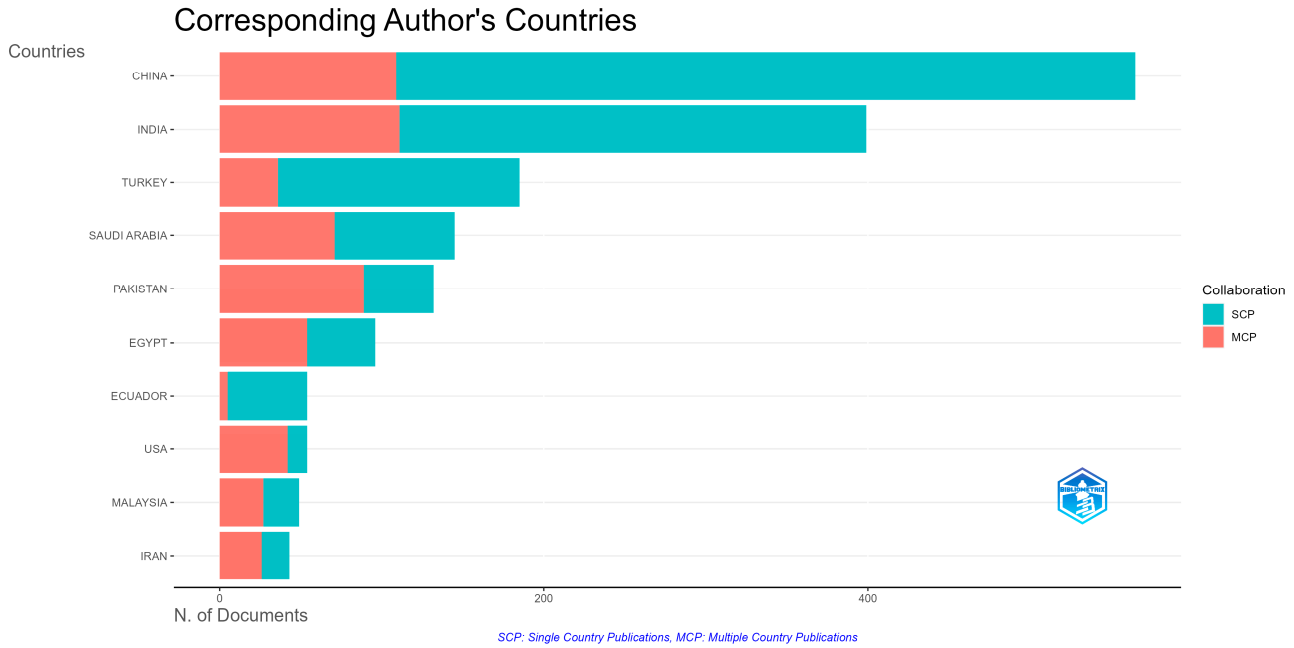

Figure 11. Top 10 most relevant corresponding authors' countries.

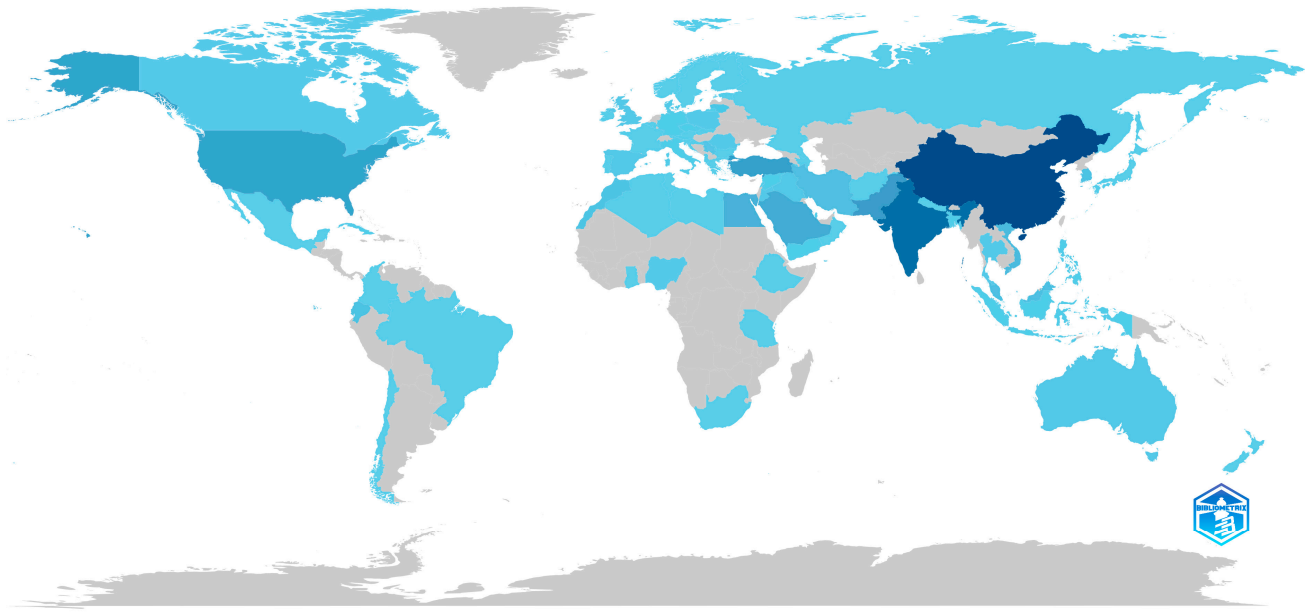

Figure 12. Scientific production based on country.

Other countries with publications in the 20–90 papers range include Ecuador (90 papers), South Korea (87 papers), Morocco (71 papers), Lithuania (62 papers), Serbia (54 papers), Australia (43 papers), Iraq (42 papers), Spain (30 papers), the UK (30 papers), Thailand (26 papers), Jordan (25 papers), Romania (23 papers), and Denmark (21 papers).

The country that wields the most substantial influence within the neutrosophic domain is China, amassing a remarkable 14,864 citations. India secures the second position, with a significantly fewer 4890 citations. Turkey occupies the third rank, with 3976 citations, followed by Egypt with 3643 citations. Among the remaining countries within the top 11, most are situated in Asia, with the exceptions of the United States and Lithuania, which exhibit relatively smaller numbers of citations. The comprehensive details for each country can be found in Figure 13.

Figure 14 illustrates a collaborative map between countries, reflecting a total of 1586 articles generated through international cooperation.

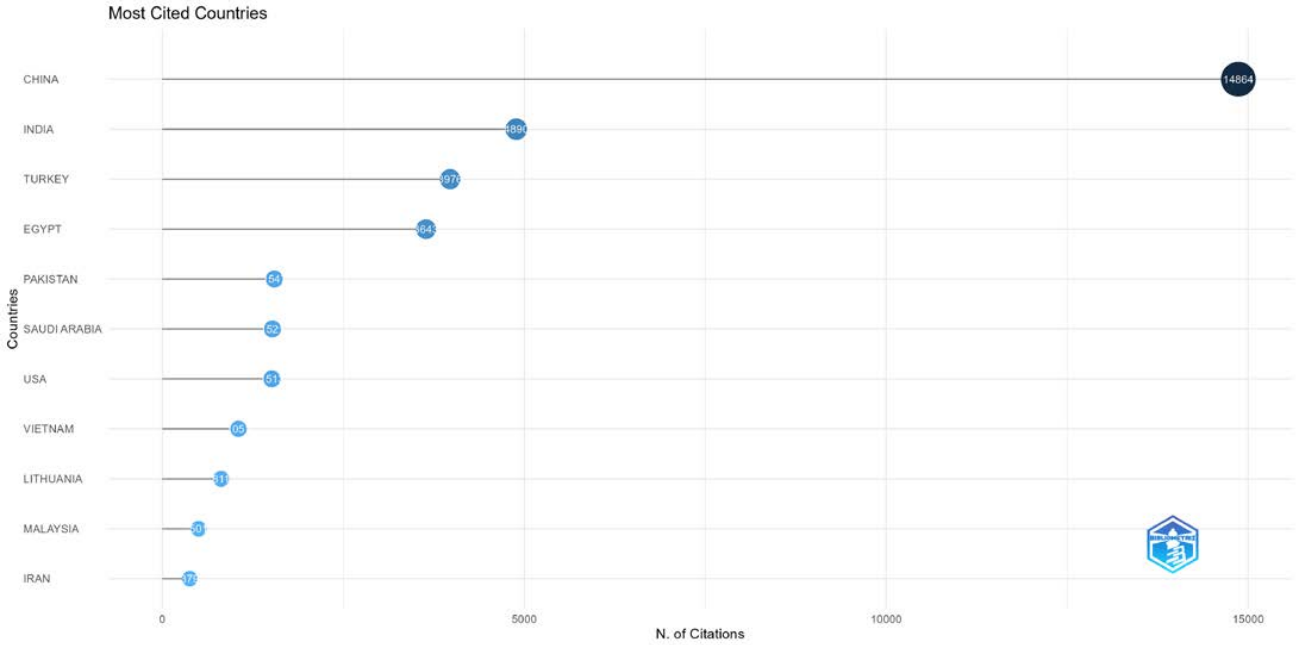

Figure 13. Top 11 countries with the most citations.

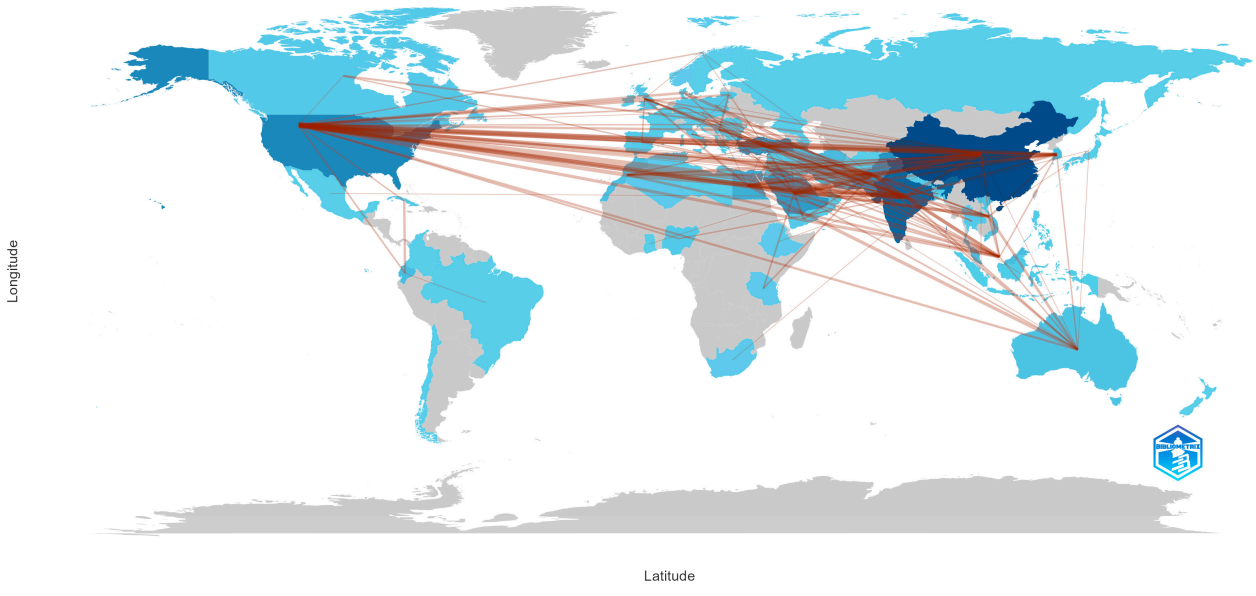

Figure 14. Country collaboration map.

The most collaborative countries in this context are Pakistan and Saudi Arabia, jointly contributing 93 papers. The second most fruitful collaboration emerges between India and the United States, culminating in 74 articles. Another noteworthy collaboration involves China and the United States, which has resulted in 66 papers. The partnership between Pakistan and the United States has produced 51 papers, while the collaboration between China and Pakistan has led to 49 articles. The United States and Egypt have jointly authored 46 articles, and India, Morocco, and Turkey have each collaborated with the United States, yielding 36 articles in each case.

Figure 15 offers an insightful depiction of the top authors' collaboration network. As anticipated, Smarandache F. stands as the central figure, attracting a significant number of authors and fostering collaborative networks.

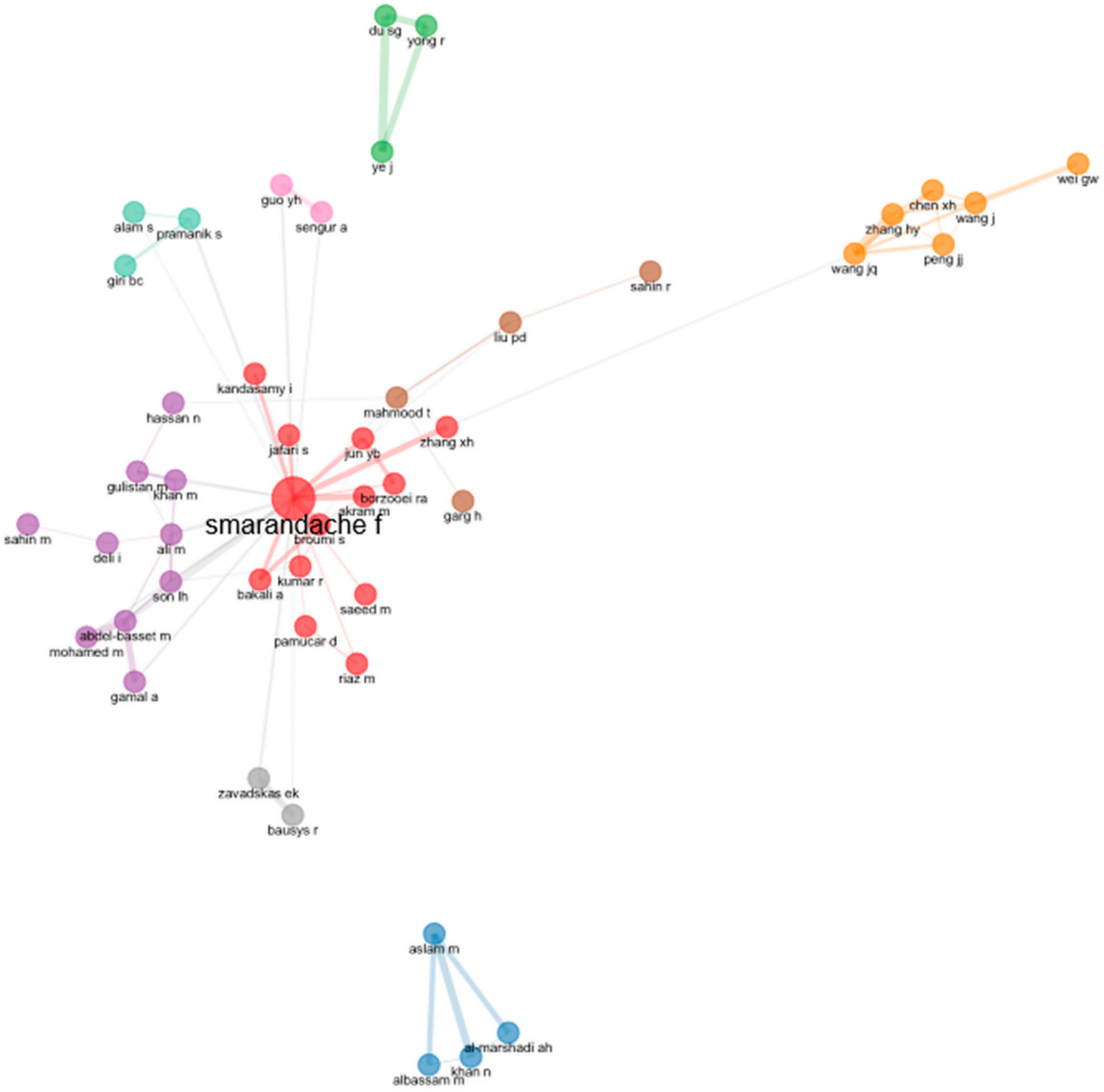

Figure 15. Top 50 authors' collaboration network.

3.4. Paper Analysis

In the forthcoming section, we will delve into the most cited articles within the neutrosophic domain, with a focus on identifying the distinct contributions of each author. This examination will span multiple domains, providing insights into the evolution of the neutrosophic field and the diverse perspectives on potential enhancements. Notably, a significant proportion of the papers in the top 10 list hail from Asia, underscoring the substantial interest and engagement with neutrosophic concepts in that region, as elaborated upon in Table 7.

The top 10 most cited global documents are summarized in Table 7, along with information regarding the number of authors, region, total number of citations, total citations per year, and normalized total citations.

Table 7 presents an overview of the most commonly encountered regions among the top-cited articles in the neutrosophic domain. Notably, China leads, with six entries, followed by India with two and Turkey, Spain, Brazil, and the UK each contributing one entry.

The most cited paper, authored by Ye [34], boasts a total number of citations (TC) of 472, with a total citations per year (TCY) of 47.20. However, the normalized total citations (NTC) for this paper are relatively low, standing at 3.13. This value is comparatively lower than the NTCs recorded for the other papers featured in Table 7. This measure helps account for variations in citation practices across different disciplines and offers a more meaningful basis for comparing citation impact [35]. The NTC metric aims to give equal credit for citations to all of the authors of the paper while accounting for the average citations per document recorded in the database for the year in which the paper was published [36]. For example, in the case of our dataset, the average number of citations per year for the 19 papers published in 2014 is 150.9. Considering the paper authored by Ye [34], which is a single-author paper and has a TC of 472 citations, the NTC was obtained by dividing the TC by the average recorded for all 19 of the papers published in the same year, namely, 150.9 citations. As a result, the NTC for Ye [34] is 3.13. Considering another paper written in 2014, the one authored by Zhang et al. [37] and placed in third position based on the TC, an NTC value of 2.46 was obtained in the same manner by dividing the TC (372 citations) by the average number of citations for 2014, namely, 150.9. In this manner, all of the authors of the paper (three in the case of Zhang et al. [37]) receive credit for all of the obtained citations, without it being necessary to further divide the obtained value by the number of authors.

Considering the paper authored by Kutlu Gündoğdu and Kahraman [38], placed in second position based on the number of citations, it can be observed that while receiving a lower value for TC than the paper of Ye [34], this paper exhibits higher values for both TCY and NTC, as detailed in Table 7. The increased TCY value is due to the reduced number of years since publication compared to Ye [34] (2019 versus 2014), while the increased NTC is due to the fact that, for 2019, the average number of citations for the 442 documents published in this year is relatively small, at 16.46. As a result, the NTC for the paper authored by Kutlu Gündoğdu and Kahraman [38] equals 386 divided by 16.46, i.e., 23.45 citations (Table 7).

Table 7. Top 10 most cited global documents.

No.	Paper (First Author, Year, Journal, Reference)	Number of Authors	Region	Total Citations (TC)	Total Citations per Year (TCY)	Normalized TC (NTC)
1	Ye, Jun, 2014, *Journal of Intelligent & Fuzzy Systems* [34]	1	China	472	47.20	3.13
2	Kutlu Gündoğdu, Fatmaa, 2019, *Journal of Intelligent & Fuzzy Systems* [38]	2	Turkey	386	77.20	23.45
3	Zhang, Hong-yu, 2014, *The Scientific World Journal* [37]	3	China	372	37.20	2.46
4	Ye, Jun, 2013, *International Journal of General Systems* [39]	1	China	326	32.91	5.40
5	Bustince, Humberto, 2015, *IEEE Transactions on Fuzzy Systems* [40]	8	Spain, Brazil, UK	309	38.63	4.86
6	Biswas, Pranab, 2016, *Springer* [41]	3	India	301	37.63	4.73
7	Ye, Jun, 2014, *Journal of Intelligent & Fuzzy Systems* [42]	1	China	289	28.90	1.91
8	Peng, Juan-juan, 2015, *International Journal of General Systems* [43]	4	China	264	33.00	4.15
9	Majumdar, Pinaki, 2014, *Journal of Intelligent & Fuzzy Systems* [44]	2	India	254	25.40	1.88
10	Liu, Peide, 2014, *Springer* [45]	2	China	244	24.40	1.62

In the following text, we undertake a critical examination of the ten most highly cited papers, as detailed in Table 6. The objective is to elucidate the contents of these papers, which have garnered significant recognition within the field of neutrosophic theory.

In the most cited paper from the extracted database, Ye [34] introduces the concept of simplified neutrosophic sets (SNSs), a subset of neutrosophic sets. SNSs are defined by having singleton subintervals within the real standard $[0, 1]$ for each of the three membership functions that typically characterize a classical neutrosophic set: the truth-membership function, the indeterminacy-membership function, and the falsity-membership function. To simplify the model further, the author assumes that the values of these membership functions are individual points within the real standard $[0, 1]$. Consequently, a set of operational relations is established based on these assumptions. Ye [34] argues that such simplification is necessary when compared to the original neutrosophic sets introduced by Smarandache [1], given the challenges associated with applying the original framework to real-world problems. To demonstrate the applicability of simplified neutrosophic sets, Ye [34] presents a decision-making scenario that involves a set of alternatives and predefined criteria with known weights. While the numerical example provided in the paper is relatively straightforward, involving only four investment companies, the author provides comprehensive explanations to ensure the reproducibility of the proposed methodology.

Among the other papers featured in the top 10 list of most cited articles, notable attention should be drawn to the papers occupying the fourth and seventh positions, both authored by the same researcher. These papers delve into the application of neutrosophic theory in the domain of decision-making. Ye's work, particularly the paper ranked fourth (Ye [39]), stands out for its real-world applications, mirroring aspects explored in the top-ranked paper (Ye [34]), yet employing distinct methodologies. In [39], the author introduces the concepts of correlation and correlation coefficient within the framework of single-valued neutrosophic sets (SVNSs). These metrics serve as tools to determine the optimal solution in an investment problem, where the evaluation hinges on measuring the correlation between each alternative and the ideal choice [39].

Regarding the paper positioned seventh in terms of citation count, authored by Ye [42], it centers on the exploration of similarity measures between interval neutrosophic sets, specifically within the context of multi-criteria decision-making. This application, akin to those discussed in the two other high-impact papers authored by Ye [34,39], entails the establishment of a ranking order for the four alternatives under consideration. This ranking is achieved by evaluating the similarity between each alternative and the ideal choice [42].

Turning our attention back to the top 10 most cited papers, the paper in the second position in terms of citations, authored by Kutlu Gündoğdu and Kahraman [38], offers a broader perspective on neutrosophic fuzzy sets (NFSs), intuitionistic fuzzy sets (IFSs), and intuitionistic fuzzy sets of the second type (IFS2s). Specifically, the authors introduce the concept of spherical fuzzy sets as a novel approach. The researchers discuss this innovative framework within the context of a supplier selection problem [38].

The paper occupying the third position in terms of citation count, authored by Zhang et al. [37], establishes fundamental operations for interval neutrosophic sets (INSs) and introduces two aggregation operators for interval neutrosophic numbers. In order to demonstrate the practicality of this approach, the authors employ a multi-criteria decision-making scenario—specifically, the one previously proposed by Ye [42]. According to the authors, the proposed approach yields results characterized by greater precision and reliability [37] when compared to the results provided by Ye [42].

The work of Bustice et al. [40], holding the fifth position based on citations, discusses the various types of fuzzy sets and their relationships. Among the identified fuzzy sets, the authors include the neutrosophic sets and state, on a historical trajectory, that the birth year for the neutrosophic sets is 2002 [40].

Biswas et al. [41] concentrated their efforts on single-valued neutrosophic sets, extending the technique for order preference by similarity to the ideal solution within the confines of a single-valued neutrosophic framework. The authors undertook a multi-attribute

decision-making problem to substantiate the viability of their proposed approach. The researchers emphasized that the concepts outlined in their paper have the potential to pique the interest of researchers in addressing decision-making challenges through the application of neutrosophic theory [41].

Peng et al. [43] discussed the issues related to the use of the simplified neutrosophic sets (SNSs) and stated the gap in the literature related to the existing operators of SNSs, their aggregation operators, and the comparison methods. As a result, the authors proposed a series of new operations of simplified neutrosophic numbers (SNNs), as well as a comparison method [43]. Through the proposed approach, the authors provided a numerical example from the area of multi-criteria group decision-making, stating that the proposed approach can represent a reliable basis for SNSs [43].

Pinaki and Syamal [44] focused on the distance between two single-valued neutrosophic sets. The authors studied the properties related to this distance and defined various similarity measures. As a result, the researchers concluded that the measures discussed in their paper are consistent with similar considerations for other sets, such as the fuzzy sets or the intuitionistic fuzzy sets [44].

Liu and Wang [45] proposed a single-value neutrosophic normalized weighted Bonferroni mean (SVNNWBM) operator for the case of single-valued neutrosophic numbers. Additionally, the authors proposed an approach to the multiple-attribute decision-making problems from the perspective of the proposed operator, accompanied by an illustrative example. Data related to the air quality in Guangzhou were used for proving the applicability of the proposed approach. The authors stated that the obtained results are comparable to those obtained by Yue [46] with the same data [45].

Upon a comprehensive analysis of the top 10 most cited papers, a recurrent theme emerges, characterized by authors' concerted efforts to address gaps in the literature pertaining to the development of novel categories of neutrosophic sets and the formulation of new operators and comparative methodologies. Moreover, it is noteworthy that the majority of these papers are accompanied by illustrative examples intended to substantiate the reliability of their proposed methodologies.

Table 8 serves as a concise repository summarizing essential information regarding the objectives of the selected papers and the datasets employed in the illustrative examples.

A critical step in bibliometric analysis is the examination of the most frequently used words, which aids in comprehending the precise vocabulary employed within the neutrosophic domain. The predominant term in keywords plus is "aggregation operators", appearing a substantial 268 times, followed by "sets", which occurs 240 times. "Model" secures the third position, with 160 occurrences, and "fuzzy", a commonly utilized technique within neutrosophy, emerges with 143 appearances. "Decision making" is prevalent, with 139 occurrences, while "similarity measures" is encountered 133 times. "Entropy", another technique employed in neutrosophy, occurs 103 times, akin to "group decision making". "Numbers" and "selection" conclude the top 10 list, with 94 occurrences each, as presented in Table 9.

Regarding "aggregation operators", it is evident that this term represents a crucial aspect when delving into the evolving field of neutrosophic theory. It plays a pivotal role by providing essential models for the amalgamation or synthesis of various considered sets into a singular set, thereby proving invaluable in addressing multi-criteria decision-making challenges. Furthermore, when examining the frequency of this bigram in titles, abstracts, and authors' keywords, it becomes apparent that "Aggregation operators" is recurrently employed, featuring 94 instances in titles, 242 occurrences in abstracts, and 26 mentions in authors' keywords.

Table 8. Brief summary of the contents of top 10 most cited global documents.

No.	Paper (First Author, Year, Journal, Reference)	Title	Data	Purpose
1	Ye, Jun, 2014, *Journal of Intelligent & Fuzzy Systems* [34]	A Multicriteria Decision-Making Method Using Aggregation Operators for Simplified Neutrosophic Sets	Synthetic data adapted from the work of Ye [39], featuring four companies in which one can invest	To define simplified neutrosophic sets (SNSs), which will take real numbers between [0, 1], including two aggregation operators, which will represent the base of the multi-criteria decision-making problem
2	Kutlu Gündoğdu, Fatmaa, 2019, *Journal of Intelligent & Fuzzy Systems* [38]	Spherical Fuzzy Sets And Spherical Fuzzy TOPSIS Method	Synthetic data related to the supplier selection problem	To apply the TOPSIS method to find the best multi-criteria decision-making solution
3	Zhang, Hong-yu, 2014, *The Scientific World Journal* [37]	Interval Neutrosophic Sets and Their Application in Multicriteria Decision Making Problems	Synthetic data adapted from the work of Ye [42], featuring four companies in which one can invest	To use interval neutrosophic sets (INSs) to demonstrate the applicability of aggregation operators in multi-criteria decision-making
4	Ye, Jun, 2013, *International Journal of General Systems* [39]	Multicriteria Decision-Making Method Using the Correlation Coefficient Under Single-Valued Neutrosophic Environment	Synthetic data adapted from the work of Ye [47], featuring four companies in which one can invest	To discover the correlation of single-valued neutrosophic sets (SVNSs) and intuitionistic fuzzy sets
5	Bustince, Humberto, 2015, *IEEE Transactions on Fuzzy Systems* [40]	A Historical Account of Types of Fuzzy Sets and Their Relationships		To analyze the relationship of properties of fuzzy sets and give examples of where sets can be applied
6	Biswas, Pranab, 2016, *Springer* [41]	TOPSIS Method for Multi-Attribute Group Decision-Making Under Single-Valued Neutrosophic Environment	Synthetic data for a multi-attribute decision-making problem with four decision-makers, six attributes and, and four alternatives.	To define opinions into one common opinion with different criteria, creating alternatives, using a single-valued neutrosophic set-based weighted averaging operator
7	Ye, Jun, 2014, *Journal of Intelligent & Fuzzy Systems* [42]	Similarity Measures between Interval Neutrosophic Sets and Their Applications in Multicriteria Decision-Making	Synthetic data adapted from the work of Ye [48], featuring four companies in which one can invest	To find a decision-making solution using interval neutrosophic values (INVs) and criterion weights, ranking alternatives
8	Peng, Juan-juan, 2015, *International Journal of General Systems* [43]	Simplified Neutrosophic Sets and Their Applications in Multi-Criteria Group Decision-Making Problems	Synthetic data adapted from the work of Gallego-Lupianez [49], featuring four companies in which one can invest and three criteria to decide upon	To identify issues in a set of certain numbers using simplified neutrosophic sets (SNSs)
9	Majumdar, Pinaki, 2014, *Journal of Intelligent & Fuzzy Systems* [44]	On Similarity and Entropy of Neutrosophic Sets	Synthetic data of single-valued neutrosophic sets	To measure the entropy using single-valued neutrosophic sets and fuzzy sets
10	Liu, Peide, 2014, *Springer* [45]	Multiple Attribute Decision-Making Method Based on Single-Valued Neutrosophic Normalized Weighted Bonferroni Mean	Data related to the air quality in Guangzhou in November 2006, 2007, 2008, and 2009, adapted from the work of Yue [46]	To solve complex decision-making problems with single-valued neutrosophic sets normalized based on a single-valued neutrosophic normalized weighted Bonferroni mean (SVNNWBM)

Table 9. Top 10 most frequent words in keywords plus.

Words	Occurrences
Aggregation operators	268
Sets	240
Model	160
Fuzzy	143
Decision-making	139
Similarity measures	133
Entropy	103
Group decision-making	103
Numbers	94
Selection	94

Furthermore, the most frequently used words in authors' keywords can provide valuable insights into the core concepts that the authors aim to convey. The prevailing term cluster in the authors' keywords is "neutrosophic set/neutrosophic sets", appearing a substantial 383 times, followed by "decision making/decision-making" with 167 appearances, a term closely associated with the decision-making domain. Then, "mcdm/multi-criteria decision-making" secures the third position, with 108 occurrences, while "topsis", a highly utilized method in the neutrosophic domain, is fourth, with 66 appearances. "Similarity measure" is recurrent, with 61 occurrences, and "single-valued neutrosophic set", a frequently employed technique, is the fifth most common, with 59 appearances. "Uncertainty" is encountered 54 times, "neutrosophic logic" is recorded 46 times, "neutrosophic soft set" is recorded 43 times, and "classical statistics" rounds out the top 10 list with 37 appearances; please consider Table 10 for further reference.

Table 10. Top 10 most frequent words in authors' keywords.

Words	Occurrences
Neutrosophic set/neutrosophic sets	383
Decision making/decision-making	167
Mcdm/multi-criteria decision-making	108
Topsis	66
Similarity measure	61
Single-valued neutrosophic set	59
Uncertainty	54
Neutrosophic logic	46
Neutrosophic soft set	43
Classical statistics	37

In Figure 16A, the top 50 words based on keywords plus are presented, with the majority of them closely associated with the neutrosophic domain. These terms include "aggregation operators", "fuzzy", "decision-making", "model", "entropy", "measured", and "operators". The frequency of each word is depicted by the font size. Once more, the pivotal role played by the aggregation operators within neutrosophic theory emerges.

In Figure 16B, the authors' keywords are featured, encapsulating the core research objectives. These keywords encompass "neutrosophic set", "decision making", "similarity measure", "neutrosophic logic", and "single-valued neutrosophic set", each serving as succinct summaries of the research focus. As depicted in Figure 16B, the "neutrosophic set" plays a key role within neutrosophic theory, encapsulating, along with "neutrosophic sets", a total of 383 occurrences in the authors' keywords.

Based on the words extracted as the top 10 most frequent words in both keywords plus and authors' keywords, it can be observed that most of them are unigrams, bigrams, and trigrams. As a result, in the following text, an analysis of the top 10 most used bigrams and trigrams in the abstracts and titles is further provided.

(**A**) Top 50 words based on keywords plus. (**B**) Top 50 words based on authors' keywords.

Figure 16. Top 50 words based on keywords plus (**A**) and authors' keywords (**B**).

Table 11 reveals that the most frequent bigrams in the abstracts and titles predominantly incorporate the keyword "neutrosophic", emphasizing the core concept within the neutrosophic domain. These frequently encountered bigrams include "neutrosophic set/neutrosophic sets", "single-valued neutrosophic", "neutrosophic soft", "valued neutrosophic", "interval neutrosophic", "neutrosophic environment", and "neutrosophic cubic". Furthermore, bigrams connected to related theories, such as "fuzzy sets", are intertwined with characteristics and attributes of neutrosophic theory, as evidenced by "single-valued" and "multiple attribute". The frequency of these top 10 most utilized bigrams in the abstracts and titles is provided in Table 11.

Table 11. Top 10 most frequent bigrams in abstracts and titles.

Bigrams in Abstracts	Occurrences	Bigrams in Titles	Occurrences
Neutrosophic set/neutrosophic sets	1330	Neutrosophic sets/neutrosophic set	271
Single-valued neutrosophic	760	Single-valued neutrosophic	188
Fuzzy sets/fuzzy set	569	Neutrosophic soft	101
Neutrosophic soft	374	Valued neutrosophic	97
Valued neutrosophic	347	Multiple attribute	95
Interval neutrosophic	338	Aggregation operators	94
Single-valued	290	Interval neutrosophic	87
Aggregation operators	272	Single-valued	80
Intuitionistic fuzzy	256	Neutrosophic environment	68
Neutrosophic cubic	226	Model-based	67

Table 12 showcases a range of trigrams present in the abstracts and titles, many of which are distinctive to the neutrosophic domain. Notable neutrosophic-specific trigrams encompass "single-valued neutrosophic", "neutrosophic hesitant fuzzy", "single-valued neutrosophic set", "single-valued neutrosophic sets", "neutrosophic set ns", "valued neutrosophic sets", "neutrosophic soft set", "neutrosophic soft sets", "neutrosophic set theory", "interval neutrosophic sets", and "simplified neutrosophic sets".

Other trigrams are aligned with the predominant problem type often addressed through neutrosophic theory, specifically, "multi-attribute decision-making", as exemplified by "multiple attribute decision-making", "multi_criteria decision_making mcdm", and "multiple attribute decision".

Table 12 furnishes the respective frequency of appearances for each of these top 10 most prevalent trigrams found in the abstracts and titles.

Table 12. Top 10 most frequent trigrams in abstracts and titles.

Trigrams in Abstracts	Occurrences	Trigrams in Titles	Occurrences
Single-valued neutrosophic	258	Single-valued neutrosophic	72
Single-valued neutrosophic set/single-valued Neutrosophic sets	190	Neutrosophic hesitant fuzzy	35
Neutrosophic soft set/neutrosophic soft sets	118	Multiple-attribute decision-making	31
Intuitionistic fuzzy sets/intuitionistic fuzzy set	139	Multiple-attribute decision	30
Neutrosophic hesitant fuzzy	112	Decision-making method based	28
Neutrosophic set ns	75	Single-valued neutrosophic sets	25
Valued neutrosophic sets	63	Interval neutrosophic sets	24
Neutrosophic set theory	57	Neutrosophic soft sets	23
Multi-criteria decision-making/MCDM	56	Simplified neutrosophic sets	19
Ideal solution TOPSIS	54	Valued neutrosophic sets	19

3.5. Mixed Analysis

Analyzing the interconnections between countries, authors, and journals serves as a valuable means of comprehending the collective attributes of authors operating within the neutrosophic field. In this regard, Figure 17 underscores that China stands as the most prominent country in this context, followed by the United States and India. Furthermore, this analysis highlights the pivotal role assumed by Smarandache F. within the neutrosophic field, showcasing his significant contributions. It also underscores the discerning choices made by authors in selecting specific journals for their publications.

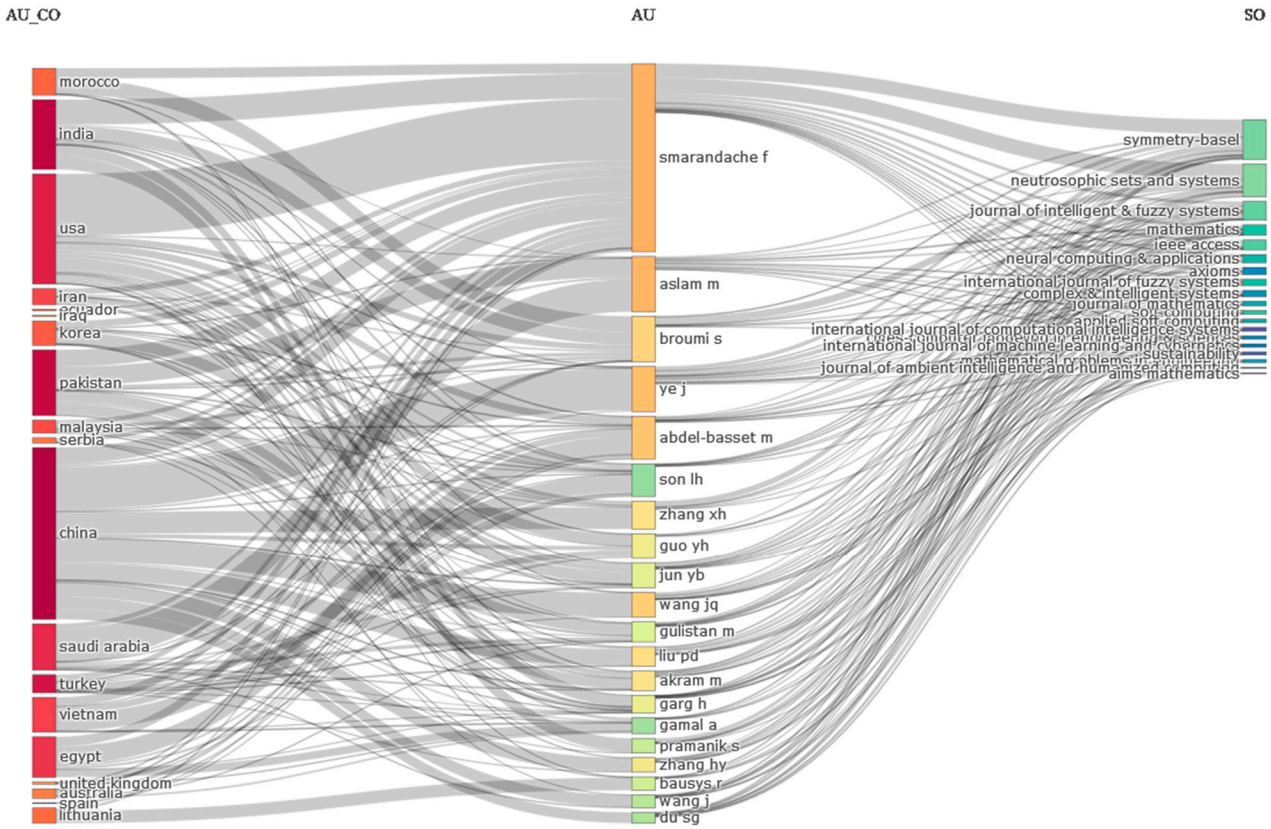

Figure 17. Three-field plot: countries (**left**), authors (**middle**), and journals (**right**).

Figure 18 offers a comprehensive view of universities, authors, and the most frequently employed keywords. The University of New Mexico emerges as the most prominent institution, featuring distinguished authors like Smarandache F., who has contributed articles encompassing decision-making and Neutrosophic sets.

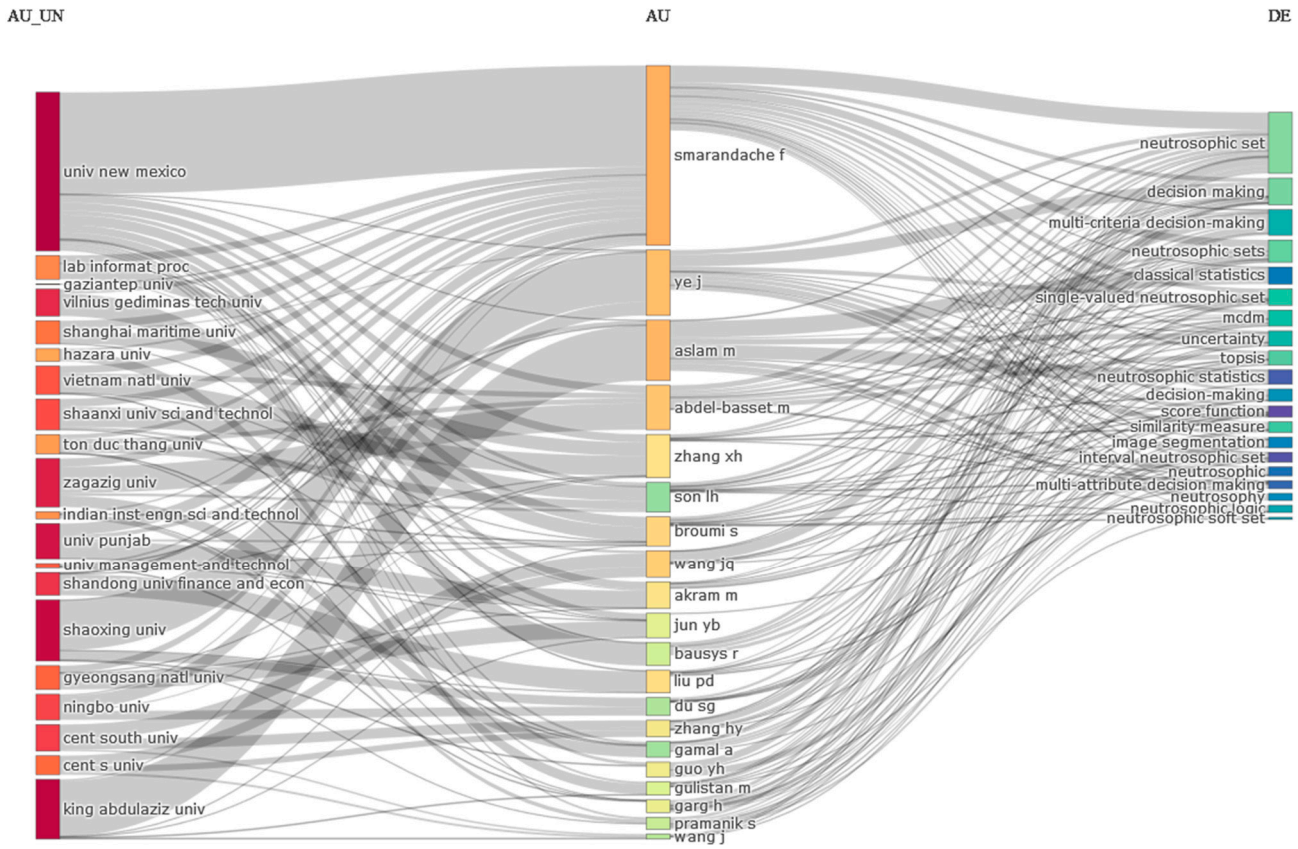

Figure 18. Three-field plot: affiliations (**left**), authors (**middle**), and keywords (**right**).

4. Discussion

The bibliometric research presented herein underscores the unsurprising prominence of Smarandache F., the pioneering figure responsible for laying the foundation of neutrosophic theory. Over the years, Smarandache F. has successfully cultivated collaborative research endeavors with scholars from across the globe, contributing to the field's expansion. As a result, through the use of the authors' collaboration network, the key role played by Smarandache F. in the creation and development of the neutrosophic field can be observed once more.

It is noteworthy that despite its relatively recent emergence, neutrosophic theory has swiftly captured the attention of researchers worldwide. Authors have disseminated their contributions in journals dedicated to well-established theories such as fuzzy theory (e.g., *Journal of Intelligent & Fuzzy Systems*, *International Journal of Fuzzy Systems*), as well as in newly established journals tailored specifically to accommodate neutrosophic theory, such as *Neutrosophic Sets and Systems*.

In a manner reminiscent of other nascent theories like grey systems, the University of New Mexico, under the aegis of the theory's originator, has emerged as a leading institution in terms of the number of neutrosophic publications.

In terms of contributing countries in the area of neutrosophic theory, China accounts for a substantial 28% of the total papers, underscoring a substantial interest among Chinese authors. The position held by China in the top-contributing countries (based on the information provided for the corresponding author) is not surprising considering that for other papers featuring theories related to neutrosophic theory, such as fuzzy sets theory, it has been observed that the top position is occupied by China. The reader can refer to the paper published by Zanjirchi et al. [50] in the area of fuzzy sets theory used in operations management, or to the bibliometric analysis conducted by Liu and Liao [51] regarding fuzzy decision research in the 1970–2015 period, which highlight the key contribution as a top country assumed by China. As Liu and Liao [51] stated, China can be observed to be

the largest producer of fuzzy decision publications, further substantiating the contribution observed even in the field of neutrosophic theory by this country.

Moreover, considering a study conducted by Peng and Dai [3], which analyzed two decades of the use of neutrosophic sets in studies from various fields, it can be observed that the top three contributing countries for the year 2017 were the same as the ones highlighted in the current study, namely, China, followed by India and Turkey.

As for the contents of the published papers in the area of neutrosophic theory, it has been observed that a recurring theme materializes in these papers, characterized by concerted efforts to address gaps in the literature, develop novel categories of neutrosophic sets, and formulate new operators and comparative methodologies.

Also, an important contribution worth mentioning is the one made by neutrosophic theory to the decision-making area. In addition to the large number of keywords extracted from the dataset related to the decision-making domain, which suggests a strong connection between neutrosophic theory and the decision-making domain, a further investigation was conducted for the purpose of properly shaping this connection. First, a thematic map was generated, which underpins the main clusters based on the authors keywords, as depicted using different colors in Figure 19. In Figure 19, we can observe five main clusters, including "neutrosophic set", "neutrosophic sets", "decision-making", "uncertainty", and "single-valued neutrosophic set", highlighting once more the contribution of neutrosophic theory to the decision-making domain.

Second, by considering the scientific literature, we tried to better identify the contributions scrutinizing prominently cited papers within the domain of neutrosophic theory applied to decision-making problems. As a result, a discernible pattern emerged, making it evident that the principal contribution of neutrosophic theory lies in the advancement and provision of diverse aggregation operators and information measures tailored for decision-making processes. Regarding the contribution of neutrosophic theory to the decision-making domain through the development of tailored aggregation operators, Peng and Dai [3] offered a comprehensive list of aggregation operators used in decision-making, along with the references to the corresponding papers. Among these operators, we can name the following: algebraic aggregation operators, basic neutrosophic aggregation operators by Bonferroni mean, neutrosophic Einstein aggregation operators, neutrosophic power aggregation operators, neutrosophic Hamacher aggregation operators, neutrosophic cloud aggregation operators, neutrosophic exponential aggregation operators, neutrosophic prioritized aggregation operators, neutrosophic Choquet integral aggregation operators, neutrosophic Heronian aggregation operators, neutrosophic correlated aggregation operators, neutrosophic Frank aggregation operators, neutrosophic Dombi aggregation operators, and neutrosophic Maclaurin symmetric mean aggregation operators [3].

Also, it is noteworthy that many of these papers substantiate their proposed methodologies with illustrative examples.

Moreover, considering the results obtained when analyzing the most used words in neutrosophic theory, it should be stated that the occurrence of several words, such as "neutrosophic set/neutrosophic sets" and "neutrosophic logic", was expected, as also depicted by the thematic map in Figure 19. First, considering the scientific literature, it can be observed that in the realm of neutrosophic theory, the neutrosophic set assumes a pivotal role, providing a formal framework through which sets articulated in a philosophical context can be extended and rigorously formalized [1,52]. Over time, various aspects related to the neutrosophic sets and their connection to real-life applications have been discussed and analyzed in the scientific literature [53–56]. In the context of theoretical advancements investigated within the realm of the scientific literature regarding neutrosophic sets, a number of extensions have been subject to comprehensive examination and scholarly deliberation [3]: single-valued neutrosophic sets [57,58], interval neutrosophic sets [49], simplified neutrosophic sets [59], neutrosophic soft sets [60,61], single-valued neutrosophic linguistic sets [62,63], multi-valued neutrosophic sets [64,65], rough neutrosophic sets [66,67], and simplified neutrosophic linguistic sets [68,69]. As for the applications of

the neutrosophic sets, it has been observed that the applications spread over a wide range of research fields including, but not limited to, decision-making [70], project management [71], medical diagnosis [72], medicine preparations [73], computing [74], pattern recognition [75], and digital image processing [76]. Second, the occurrence of the term "neutrosophic logic" within the authors' keywords is in line with the expectations given the body of the scientific literature. Generally, the neutrosophic logic defines each variable, x, through an ordered triple $x = (t, i, f)$, in which t represents the degree of truth, i describes the level of indeterminacy, and f refers to the degree of falsity [52]. As the three abovementioned components are independent, three possible outcomes can be encountered, depending on their superior sum: incomplete information, when their superior sum is <1; contradictory (paraconsistent) information, when their superior sum is >1; and complete information, when the sum is equal to 1 [52]. Furthermore, considering the nature of the three components, it should be noted that they are not necessarily intervals, and they can take the form of any real sub-unitary subset [52], which has proven to be helpful in addressing real-life problems, placing "neutrosophic logic" among the top 10 most used keywords in the selected dataset.

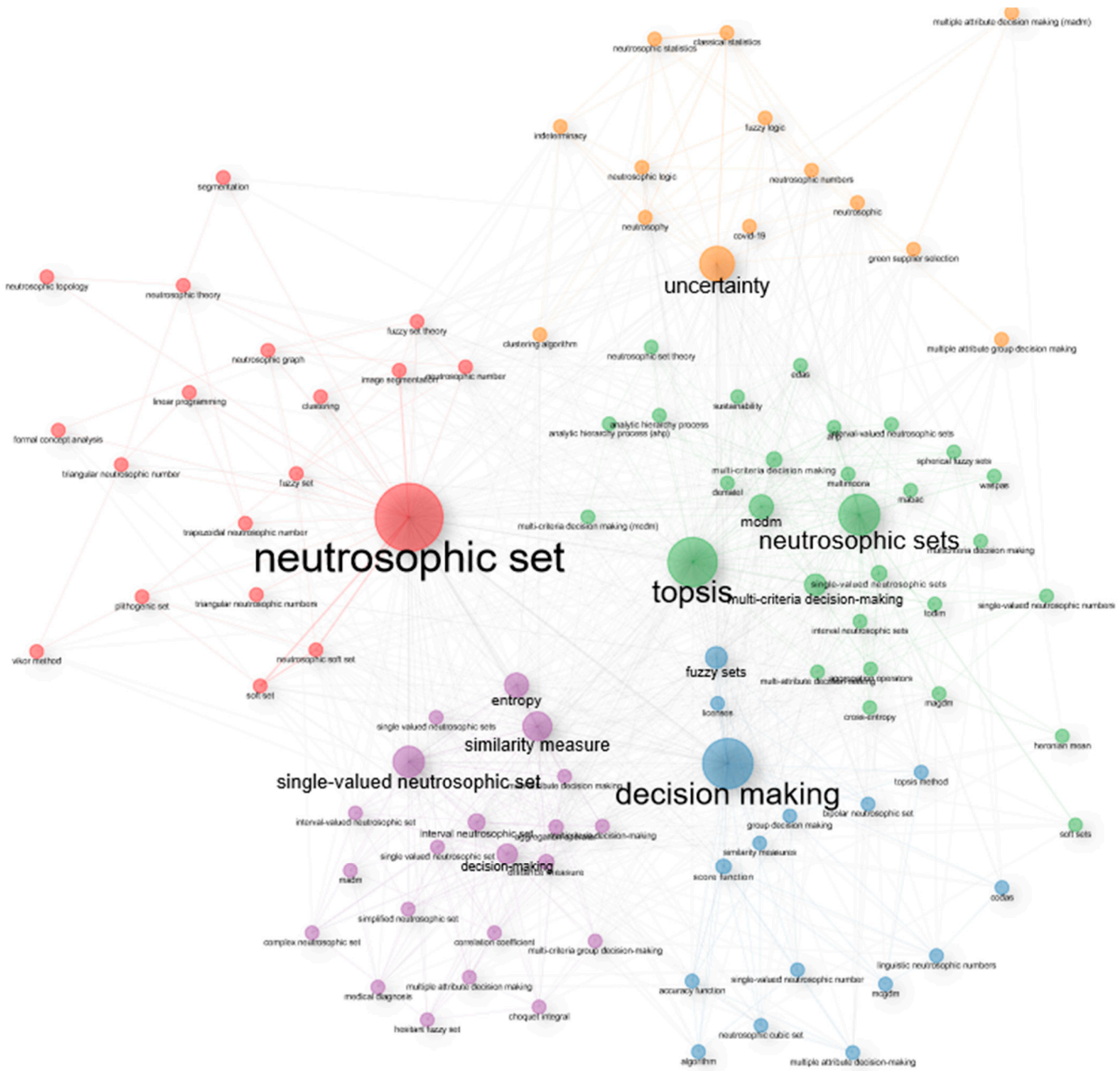

Figure 19. Thematic map based on authors' keywords.

Given the elements highlighted in the bibliometric analysis, the evolution of and the main contributors to neutrosophic theory have been highlighted, offering a multifaceted view on this research field, which has brought important contributions to various research fields over time.

5. Limitations

This paper is subject to certain limitations, primarily stemming from the process of dataset selection. First and foremost, the choice of the database introduces a constraint. While WoS is widely recognized and held in high regard within the academic community, the omission of other databases may impact the size and diversity of the selected dataset. Furthermore, as pointed out by Liu [30], the use of the search terms offered by the WoS platform comes with a series of limitations. For example, the author observed that, for the papers published before 1990, there is an extremely low availability rate for the abstracts, author keywords, and keywords plus, which might impact the results obtained through searching within these fields. Some of the causes are related to the papers' information collection process conducted by WoS from the journals, or to the limited/no availability of this information at the journal level [30]. With all of these, Liu [30] highlights the fact that the availability rates for the abstracts, author keywords, and keywords plus have gradually improved over the past two decades. As the paper written by Liu [30] dates from 2021 and the dataset extracted for the current paper starts in 2005, we expect the dataset to be influenced to some extent by the limited availability of the papers' abstracts, author keywords, and keywords plus. As shown in the paper, we identified only 169 cases in which the authors' keywords were missing and we have clearly stated the encountered situation in the paper, offering some updated results for the case in which we would have eliminated these 169 papers from the dataset.

Furthermore, the predefined search criteria applied during the extraction of the papers from WoS present another set of limitations. These restrictions encompass the language of the papers, which was confined to English, the paper type, restricted to articles (excluding other paper types, such as conference papers), and the specific keywords utilized for paper retrieval. In terms of the papers' language, we have to mention that, as the search was restricted to English, the extracted database is not affected by the disparity between the WoS and Scopus databases pointed out by Vera-Baceta et al. [77]. Considering the study conducted by Vera-Baceta et al. [77], the authors observed a disparity between the WoS and Scopus for non-English papers, namely, that Scopus tends to have a greater coverage than WoS in terms of non-English papers.

Also, we have to point out that any alteration of the search parameters, the considered database, or the exclusion criteria could potentially yield a different final dataset.

6. Conclusions

This paper delves into the advancements within the field of neutrosophic theory, as evidenced by the number of published papers, citation patterns, authorship dynamics, collaborative networks, and prevalent sources among articles indexed in the WoS platform.

Given the contribution of the neutrosophic field to decision-making and the advancements made by the neutrosophic field in both theory and practice, as well as the increased interest of researchers worldwide in this field (observed through both an increase in the number of published papers and the significant numbers of citations obtained for the papers featuring the use of this theory), we anticipate a sustained and enduring interest from the academic community, facilitated by its ease of comprehension and its manifold real-life applications, particularly in the context of multi-criteria decision-making.

Future work will delve deeper into the extensive array of real-life applications wherein neutrosophic theory has demonstrated its efficacy. This analysis will seek to elucidate the key factors that have motivated researchers to embrace neutrosophic theory. Additionally, this examination can be augmented through analogous analyses conducted on well-established databases, such as Scopus.

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