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REVIEW

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A Bibliometric Analysis of Linguistic Variables Based on Intuitionistic Fuzzy Set

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Abstract: The intuitionistic fuzzy set (IFS) has been extensively investigated, particularly concerning linguistic variables. Therefore, several modifications of linguistic variables based on IFS have been proposed in the literature. This study aims to explore scientific data related to linguistic variables based on IFS through bibliometric analysis. Data were obtained from the Scopus database and analyzed using VOSviewer software to evaluate the structure, conceptual evolution, and trends. The Scopus database provided 329 documents spanning the years 2002–2024. Specifically, the study examines the distribution of published documents per year, the most frequent keywords, the most influential authors, and the most frequently referenced sources. By highlighting significant articles and outlining publication topics, this analysis helps to enhance the quality of reviews in this field. This bibliometric analysis provides valuable insights for researchers and practitioners interested in utilizing linguistic variables based on IFS, offering an overview of current research trends and suggesting potential directions for further study.

Keywords: linguistic variables, intuitionistic fuzzy set, uncertainty, bibliometric analysis, Scopus, VOSviewer

1. Introduction

As decision-making processes become more complex, involving subjectivity, inadequate knowledge, measurement errors, and other uncertainties, information becomes inaccurate, unclear, or ambiguous. Many decision-making models presented in the literature aim to address these problems by integrating with fuzzy set (FS) theory, first introduced by Zadeh [1]. In FS theory, each element in a set is assigned a membership degree (MD), a value within the interval [0, 1] and complemented by a non-membership degree (NMD). Initially, these MD and NMD were considered precise values. However, subsequent research has highlighted situations where knowledge is indeterminate or incomplete, extending beyond the complementary nature of MD and NMD. Atanassov [2] proposed the intuitionistic fuzzy set (IFS) as an extension of FS theory. In IFS, MD and NMD can independently vary within the unit interval, and their sum can be less than one. Additionally, the concept of hesitancy degree was introduced to further capture uncertainties in decision-making.

In numerous practical decision-making situations, utilizing linguistic information is both suitable and straightforward due to the diverse nature of the problems. The fuzzy linguistic approach is a popular method for modeling linguistic information, addressing uncertainty through FS theory. Zadeh [3] initially defined the concept of a linguistic variable as one whose values consist of words or sentences in a natural or artificial language, rather than numerical values. The fuzzy linguistic approach has been expanded into several types of models, including the semantic model [4], the symbolic model [5, 6], and the 2-tuple fuzzy linguistic representation model [7, 8]. This approach has found application across various fields, including industry-education integration [9], student satisfaction [10], software development [11, 12], automotive industry [13], random variate generation [14], risk management [15, 16], equity crowdfunding and family firms [17], and stakeholder prioritization [18]. Multi-criteria decision-making methods using linguistic variables have been applied in various contexts, such as renewable energy evaluation [19], hold baggage security screening systems [20], autonomous vehicle driving systems [21], emergency suppliers [22], and business intelligence [23]. However, these extended models have significant limitations because they evaluate a linguistic variable using only a single linguistic term rather than considering the detailed information provided by decision-makers about the variable.

Since decision-makers may need to consider multiple terms simultaneously or require a complex linguistic description, relying on a single linguistic term can frequently be inadequate or challenging to determine. Fuzzy linguistic variables are limited in that they only consider linguistic MD, thus failing to fully capture the complexity of human linguistic expressions, which commonly involve uncertainty and hesitation. Wang and Li [24] presented the linguistic IFS (LIFS), which was inspired by linguistic FS and IFS. LIFS provides an alternative and more effective way to represent decision-makers' preferences during the decision-making process. It encompasses not only the notions of MD but also the evaluations of NMD and hesitancy that mimic human cognitive processes for assessing uncertainties. The linguistic approach to IFS, introduced by Zhang [25], expanded the scope of linguistic modeling by

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applying it to multi-attribute group decision-making (MADM). Based on intuitionistic linguistic numbers for decision-making, Liu and Shen [26] proposed an extended TODIM approach, while Ou et al. [27] applied the TOPSIS technique to group decision-making. Garg and Kumar [28] presented an MADM method based on the set pair analysis theory in an LIFS environment. Wu et al. [29] proposed a group decision-making method utilizing LIFS, structural entropy weights, and TOPSIS for emergency plan decisions in waterlogging disasters at subway station projects. The distance measure of LIFS was proposed by Kumar and Chen [30], using linguistic intuitionistic fuzzy numbers to express the MD and NMD of each element in the universe. These advancements include various extensions such as 2-tuple LIFS [31], linguistic interval-valued IFS [32], linguistic trapezoidal fuzzy IFS [33], and linguistic hesitant IFS [34].

Considering the widespread use of linguistic variables based on IFS and the ongoing developments since its inception, it is essential to provide a thorough overview of the latest trends in research. Therefore, bibliometric analysis is receiving more attention for analyzing published scientific articles and interpreting the results both statistically and visually [35]. The advantage of bibliometric analysis lies in its ability to construct a broad overview of a study field, enabling the analysis of specific aspects such as articles, journals, authors, institutions, and countries [36]. It is also available for numerous databases and software, allowing the analysis of large volumes of data. In earlier research, Yu and Shi [37] examined the evolution of IFS using bibliometric analysis techniques. Yu et al. [38] presented a scientometric review of IFS studies to identify the most cited papers, influential authors, and prominent journals. He and Wu [39] identified and investigated the 100 most commonly cited publications on IFS using bibliometric analysis. However, these three studies on IFS used research documents only from the Web of Science (WoS) database.

Nonetheless, as far as we are aware, no bibliometric analysis has been performed on IFS in the context of linguistic variables, especially using the Scopus database in the existing literature. The aim of this paper is to address this gap by providing an extensive bibliometric analysis of the literature on linguistic variables based on IFS. To achieve this, we extensively collected literature associated with linguistic variables based on IFS from Scopus databases. Therefore, the objectives of this paper are (i) to examine the trends and effectiveness of publications about linguistic variables based on IFS using bibliometric analysis; (ii) to facilitate the sorting of articles based on the number of published documents per year, the most frequent keywords, the most influential authors, and the most frequently referenced sources; (iii) to address clusters analysis based on an examination of the keywords and terms found in titles abstracts and keywords; and (iv) to outline the distribution and future directions of research on linguistic variable based on IFS.

This paper is structured as follows: Section 2 provides related works. Section 3 describes the materials and methods used. Section 4 presents the analysis, results, and discussions derived from the bibliometric analysis. Lastly, Section 5 discusses the future research and conclusion.

2. Literature Review

One popular and reliable technique for reviewing and analyzing large amounts of scientific data is bibliometric analysis [40]. Bibliometric analysis involves the quantitative analysis of articles published in a scientific field, providing a detailed overview of the knowledge structure, assessment, and measurement [41]. It is particularly useful for compiling a collection of materials that offers a broad picture of popular trends. Through this quantitative analysis, bibliometric analysis evaluates academic output based on journals, citations, co-citations, authorship, and keywords, in addition to examining the growth and distribution of bibliographies [42–44]. Bibliometric research has been conducted in several fields, including health and medicine [45], social sciences [46], computer science [47], mathematics education [48], environmental science [49], geotourism [50], and digital entrepreneurship management [51].

In the current literature, bibliometric analysis is a research field that is receiving growing interest from researchers, especially in the context of fuzzy research. This includes a general overview of fuzzy portfolio research [52], fuzzy research [53], fuzzy logic research [54, 55], and fuzzy-set qualitative comparative analysis [56]. More generally, existing bibliometric studies have investigated specific fuzzy linguistic subfields and themes, such as fuzzy linguistic knowledge domain [38], 2-tuple linguistic mode [57], linguistic studies on social media [58], and linguistic research on COVID-19 [59]. In this section, we present relevant reviews and research on bibliometric analysis in the context of linguistic variables and FS, with a summary of the findings provided in Table 1.

Table 1
Review of related works

Authors	Research purpose	Types	Year of period	Database	Type of review	Software
Morente-Molinera et al. [60]	Offer insights into the development of multi-granular fuzzy linguistic modeling techniques	Multi-granular fuzzy linguistic modeling	Not applicable (NA)	WoS	Systematic review	NA
Liao et al. [61]	Present a detailed bibliometric review of hesitant FS	Hesitant FS	2009–2018	WoS	Bibliometric analysis	VOSviewer and CiteSpace
Chen et al. [62]	Maps the knowledge domain of fuzzy linguistic research for scientometric analysis	Fuzzy linguistic research	1975–2018	WoS	Scientometric review	CiteSpace

(*Continued*)

Table 1
(*Continued*)

Authors	Research purpose	Types	Year of period	Database	Type of review	Software
Lin et al. [63]	Conduct a thorough analysis of Pythagorean FS to gain a complete understanding of their historical development, current status, and future trends	Pythagorean FS	2013–2020	WoS	Biblio-metric analysis	VOSviewer and CiteSpace
Shukla et al. [64]	Utilized bibliometric methods to achieve a broad overview of the type-2 FS and systems field	Type-2 FS and Systems	1997–2017	WoS, SCI-E, SSCI, and ESCI	Biblio-metric analysis	VOSviewer
Alfaro-García et al. [65]	Provide a broad overview of how FS theory impacts academics and various scientific fields	FS theory and its applications	1970–2014	WoS	Biblio-metric analysis	VOSviewer and CiteSpace
Yu et al. [38]	Examine the knowledge structure and citation patterns using scientometric and bibliometric methods	Fuzzy linguistic knowledge domain	1975–2018	WoS	Biblio-metric analysis	CiteSpace
Laengle et al. [66]	Provide a bibliometric summary of key trends by analyzing the most productive and influential authors, institutions, and countries, along with the publication and citation patterns	FS and systems	1978–2016	WoS	Biblio-metric analysis	VOSviewer and SciMAT
He and Wu [39]	Identify and examine the most cited publications in the field of intuitionistic FS	Intuitionistic FS	All years	SSCI, and WoS	Biblio-metric analysis	NA
de Andrés-Sánchez [67]	Conduct a systematic bibliographi-cal analysis of FS theory on option pricing to focus and address the fundamental questions regarding the analytical foundations of the reviewed approaches	FS theory	2001–2022	Scopus and WoS	Systematic review	PRISMA

3. Materials and Methods

Scopus is recognized as the greatest database of abstracts, citations, and keywords for peer-reviewed research across a variety of scientific fields. In this study, data for the bibliometric analysis were obtained from Scopus using the following search terms: (TITLE-ABS-KEY (linguistic AND variable) OR TITLE-ABS-KEY (linguistic AND term) AND TITLE-ABS-KEY (intuitionistic AND fuzzy AND set)). A total of 329 publications related to linguistic variables based on IFS were identified in the Scopus databases. These publications include journal articles, conference papers, book reviews, and other types of studies.

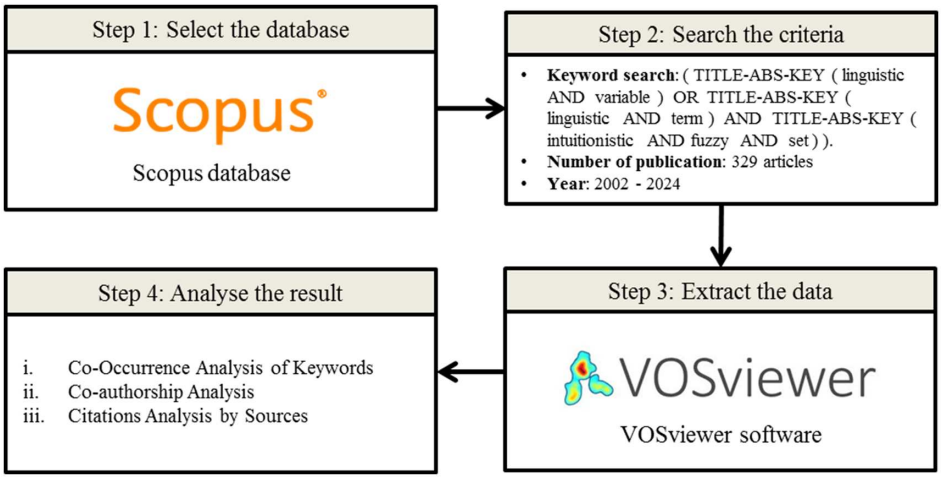
To illustrate the findings of bibliometric analysis, a variety of bibliometric tools are available, such as BibExcel, Biblioshiny, BiblioMaps, CiteSpace, CitNetExplorer, SciMat, SCiTool, and VOSviewer [68]. The VOSviewer software, designed by van Eck and Waltman [69], is a tool for the formation and visualization of bibliometric networks to analyze intellectual groups, including clustering solutions. This software enables effective literature compilation and facilitates the determination of how selected publications relate to one another. Throughout the investigation, this approach was also employed to gather information on the origins, growth, and trends within the field of study. This was achieved by incorporating a variety of scientific publishing components, including authors, journals, keywords, references, institutions, and other bibliographic characteristics [70, 71].

The software employs numerous bibliometric techniques to analyze the result, including co-occurrence, co-authorship, and citation analysis. It is noteworthy that the rapid advancement of bibliometric tools has significantly simplified the process of conducting bibliometric studies. Therefore, all documents listed in the Scopus databases were analyzed using the VOSviewer software tool, which is utilized for constructing and visualizing bibliometric networks. The process of bibliometric analysis in this study is illustrated in Figure 1.

4. Analysis, Results, and Discussion

This study utilizes bibliometric analysis to explore the effectiveness and trends of publications related to IFS theory based on linguistic variables. A bibliometric analysis was conducted on a total of 329 publications from scientific papers indexed in the Scopus database between 2002 and 2024. Each document listed in the Scopus database was examined using the VOSviewer software. VOSviewer enables the investigation of bibliometric networks in five different ways: co-occurrence, co-citation, co-authorship, bibliographic coupling, and citation. This analysis allows the sorting of

Figure 1
Process of bibliometric analysis



articles according to keywords, documents, source types, authors, organizations, countries, and references. Bibliometric data can be graphically analyzed, and study findings can be visually represented using the VOSviewer software. Each item in the network visualization is represented by a label and circle, where the circle's size reflects the quantity of publications associated with that particular item. The larger the circle and label, the more publications linked to the item. Colors correspond to groups of terms clustered together, while the length of curved lines indicates the approximate frequency of term repetition. Additionally, the thickness of the lines denotes the strength of connections between pairs of topic areas or keywords.

In this study, four kinds of analytical approaches are applied: the number of publications by year, co-occurrence analysis (examining relationships among keywords), co-authorship analysis (exploring the interrelatedness of authors), and citation analysis (evaluating sources within specific journals or journal categories).

4.1. Number of publications by year

The number of documents published each year from 2002 until recently is represented in Figure 2. In the initial period from 2002 to 2009, there was consistently low publication on the linguistic variable of IFS, fluctuating from zero to a few documents per year. There has been a gradual increase in the number of documents, with a noticeable but moderate rise starting around 2010 and continuing through 2016, peaking at just under 22 documents. This significant increase in publications can be attributed to the growing interest of researchers in implementing linguistic variables of IFS from 2017 onward, with peaks and troughs. The peak occurred in 2018 with about 43 documents. There is a noticeable dip in 2019, followed by another peak around 2021. Overall, the trend indicates an initial period of low publications, followed by a period of growth and fluctuation. It is anticipated that research trends related to the linguistic variable of IFS will continue to increase in 2024.

4.2. Co-occurrence analysis of keywords

VOSviewer software was used to conduct co-occurrence analysis, with all keywords serving as the unit of analysis. In this section, we analyze bibliometric mapping, where each node signifies a keyword connected to others. Larger nodes indicate higher frequency or prominence of keywords. All keywords used in the full counting method were included in the analysis during the co-occurrence mapping process. To achieve more accurate results, the study applied certain constraints, including a minimum number of occurrences, as a limiting factor to modify the number of keywords.

A total of 1887 keywords were found, with only 123 meeting the threshold of five to indicate the creation of two closely linked clusters among their nodes. The size of the circle corresponds to how frequently the related keyword appears. The color indicates the cluster in which the keyword appears according to the quantity of co-occurrences. Furthermore, when two keywords are close to one another, their distance indicates a high number of co-occurrences of the keywords. Figure 3 presents the co-occurrence analysis of keywords linguistic variables based on IFS.

This software evaluates each keyword by determining its cluster color, occurrence, and total link strengths with other keywords. An occurrence indicates the number of publications in which the keyword is found. Based on Figure 3, the co-occurrence analysis was distributed among six clusters. Cluster 1 (red) focuses on core topics such as decision-making, linguistic terms, and entropy. Cluster 2 (green) includes topics related to FS, IFS, and numerical methods. Cluster 3 (blue) stands for linguistics, mathematical operators, group decision-making, and IFS. Cluster 4 (yellow) consists of topics related to IFS, aggregation operators, and linguistic variables. Cluster 5 (purple) involves intuitionistic fuzzy numbers and fuzzy rules. The other colors represent additional clusters, each with own specific focus areas. Thicker lines between nodes indicate stronger co-occurrence relationships.

The most prominent keyword is "fuzzy sets" (225 occurrences), which has the highest number of co-occurrences and largest nodes in the network, highlighting the central theme of the literature. Overall, the figure provides a visual representation of the key concepts and their relationships within the field of FS, helping to identify major themes and research trends. Table 2 lists the top 15 most frequent keywords.

4.3. Co-authorship analysis

Co-authorship analysis provides insights into the relationship among authors who collaborate within this research field. This analysis is crucial for assessing the performance and visibility of the authors and their research over the years. Out of the 736 authors

Figure 2
Number of publications by year

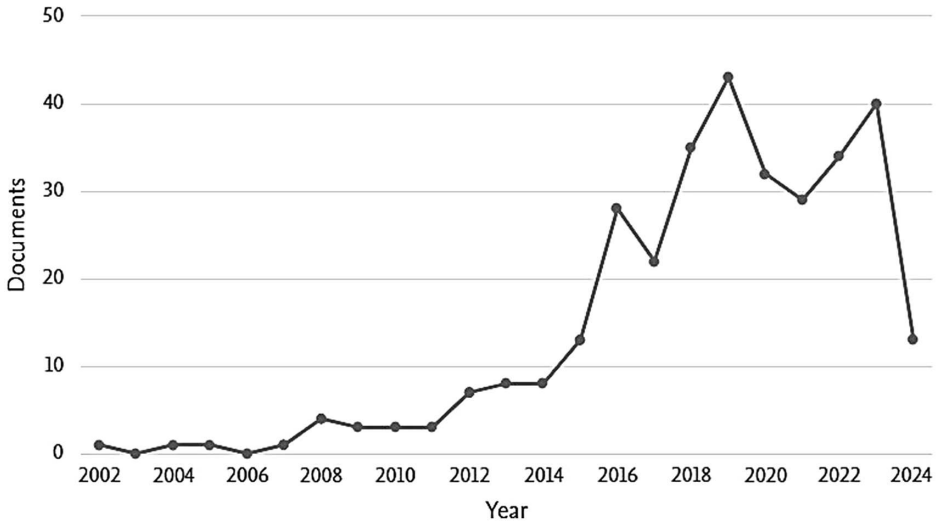
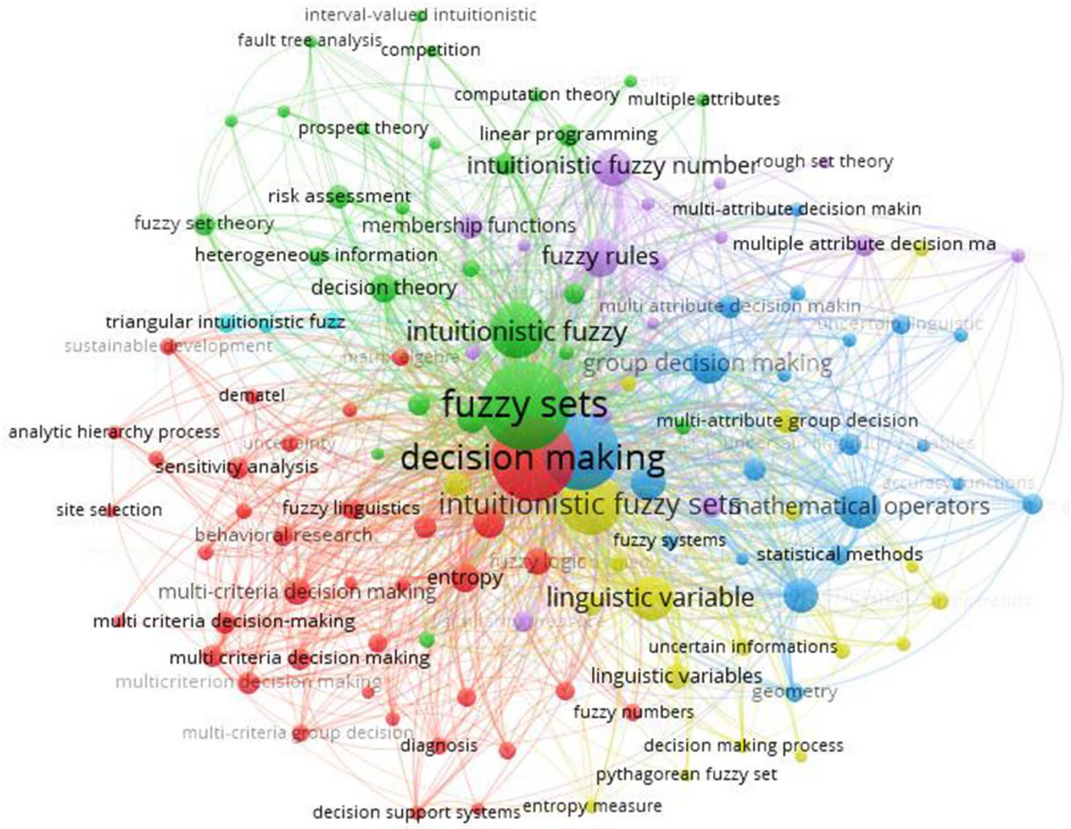


Figure 3
Co-occurrence analysis



in this database, only 119 have either co-authored or independently produced two documents. Figure 4 illustrates the co-authorship relationships among researchers in this field. Each node represents an author, with the size of a node indicating the number of publications or the prominence of the author within the literature. Larger nodes indicate more influential authors.

The authors are grouped into clusters based on their co-authorship patterns. Each cluster is shown in a different color, representing groups of researchers who frequently collaborate with each other. Among the five clusters (red, green, blue, yellow, and purple), Cluster 1 (red) is the most extensive, comprising six authors: Liu Peide, Li Junqing, Liu Zhengmin, Qin Xiyou, Xu Hongxue, and Zhang Xiaohong. Cluster 2 (green) includes six authors: Chen Shyi-ming, Ma Beiling, Meng Fanyong, Tan Chunqiao, and Yuan Ruiping. Cluster 3 (blue) comprises authors such as Agarwal Nikunj, Merigó José, Naqvi Deeba, Sachdev Geeta,

Table 2
Most occurrence keywords

Keywords	Cluster number	Occurrences	Total link strength
Fuzzy sets	Cluster 2	225	1642
Decision-making	Cluster 1	205	1604
Linguistics	Cluster 3	172	1333
Intuitionistic fuzzy sets	Cluster 4	107	778
Intuitionistic fuzzy	Cluster 2	87	662
Linguistic variable	Cluster 4	56	447
Mathematical operators	Cluster 3	55	484
Group decision-making	Cluster 3	44	344
Intuitionistic fuzzy number	Cluster 5	43	365
Fuzzy rules	Cluster 5	41	345
Aggregation operators	Cluster 4	36	314
Intuitionistic fuzzy set	Cluster 3	36	250
Linguistic terms	Cluster 1	31	238
Numerical methods	Cluster 2	25	206
Entropy	Cluster 1	24	211

and Verma Rajkumar. Cluster 4 (yellow) contains authors like Faizi Shahzad, Rashid Tabasam, Salabun Wojciech, Shah Mubashar, and Zafar Sohail. Cluster 5 (purple) features Abdullah Lazim, Garg Harish, Kumar Kamal, and Zamri Nurnadiah. Relationships between co-authors are shown by the lines connecting nodes. Stronger collaboration is shown by thicker lines, which identify authors who have co-authored several publications.

The most prominent author, indicated by a larger node, is Liu Peide, who has published 18 articles and received 1076 citations, demonstrating significant influence in the field. Liu Peide also has eight connections indicating collaborations with other authors. Figure 4 summarizes the co-authorship analysis in this field, highlighting prominent authors, significant research collaborations, and the structure of research partnerships. This figure facilitates the identification of significant contributors and the extent of researcher collaboration. Table 3 lists the top 15 most influential authors based on their total number of publications and citations.

Table 3
Most influential authors

Author	Documents	Citations	Total link strength
Liu, Peide	18	1076	8
Garg, Harish	12	553	9
Kahraman, Cengiz	9	265	7
Rashid, Tabasam	9	170	15
Kumar, Kamal	8	384	8
Meng, Fanyong	8	182	10
Abdullah, Lazim	8	70	3
Xu, Zeshui	7	606	8
Faizi, Shahzad	7	118	16
Xian, Sidong	6	143	7
Abdullah, Saleem	6	118	10
Verma, Rajkumar	6	84	4
Liu, Hu-chen	5	545	4

4.4. Citations analysis by sources

The network visualization of citation relationships among academic journals in this research field was created using VOSviewer. Each node represents an academic journal, with its size indicating the frequency of its citation. Larger nodes indicate a higher number of citations from sources. In this study, there are 167 sources with a minimum of five documents and zero citations. These analyses aim to provide a more accurate understanding of sources with the highest number of publications and citations. Figure 5 illustrates the analysis of publication citations by source.

The sources are grouped into different colors of clusters based on citation patterns. Figure 3 is divided into four clusters: Cluster

Figure 4
Co-authorship analysis

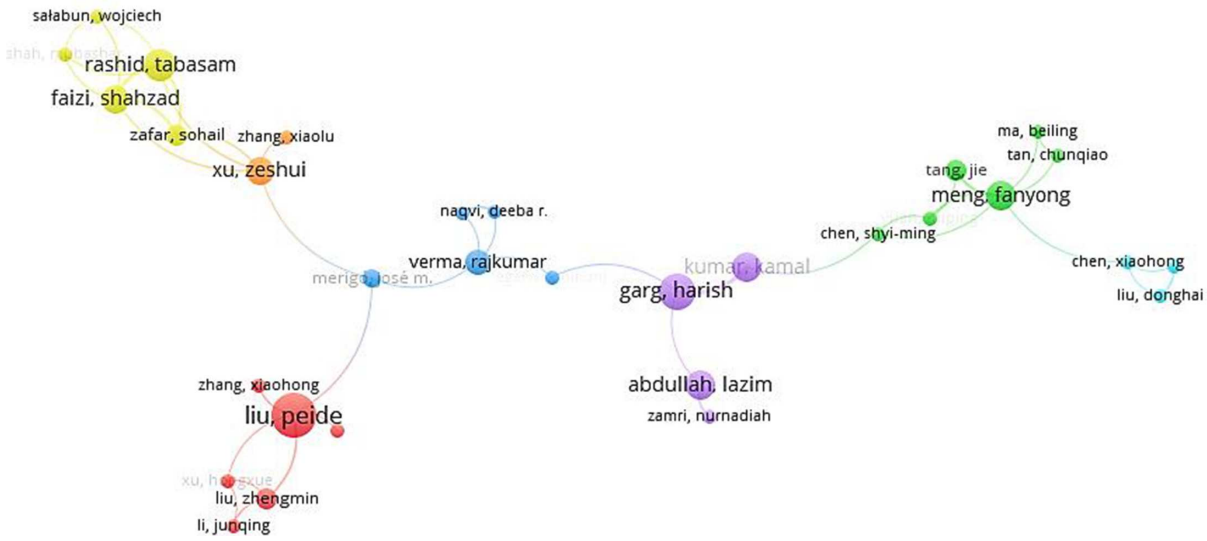
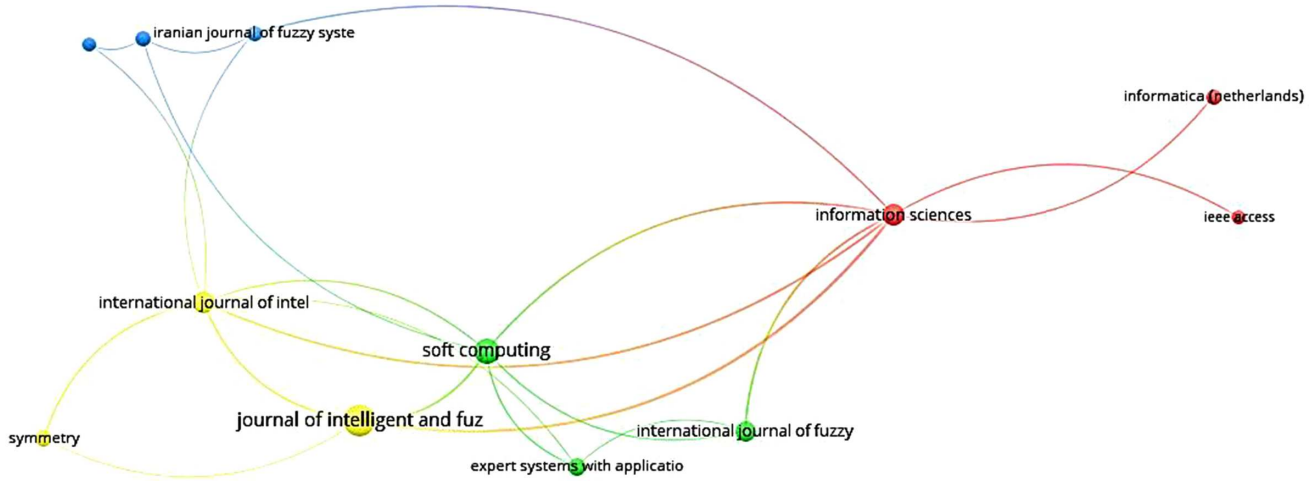


Figure 5
Citation analysis by source



1 (red) contains journals such as Information Sciences, Informatica (Netherlands), and IEEE Access. Cluster 2 (green) consists of three journals: Soft Computing, Expert Systems with Applications, and International Journal of Fuzzy Systems. Cluster 3 (blue) includes journals like the Iranian Journal of Fuzzy Systems, Communications in Computer and Information Science, and Neural Computing and Applications. Cluster 4 (yellow) consists of the Journal of Intelligent and Fuzzy Systems, International Journal of Intelligent Systems, and Symmetry. Thicker lines between nodes represent the stronger citation relationship, indicating sources that are frequently cited together in the literature.

Information Sciences is the most frequently cited source, with the largest number of citations (900) and a total link strength indicator of 23. It appears to be central in the network, indicating it has strong connections with multiple other journals across different clusters. Overall, this figure presents an overview of citation analysis by sources in the field, highlighting important journals, significant sources of scholarly impact, and the structure of academic citations. It aids in locating key journals and the citation trends connecting many fields of study. Table 4 lists the most cited relationships among sources.

5. Future Research

The study primarily focuses on analyzing the evolution and development of this research field concerning articles, journals, and authors. Therefore, this paper provides a general bibliometric overview of linguistic variables based on IFS. However, it is important to acknowledge certain limitations. The limitation of our study is that we did not compare the Scopus database with other, more comprehensive databases. Future research can build upon this paper by including data from other scientific databases, such as WoS,

Table 4
Most citation by sources

Sources	Documents	Citations	Total link strength
Information Sciences	11	900	23
International Journal of Intelligent Systems	11	634	16
Soft Computing	15	447	14
Journal of Intelligent and Fuzzy Systems	23	422	15
Expert Systems with Applications	8	319	4
International Journal of Fuzzy Systems	10	212	7
Neural Computing and Applications	6	192	3
Iranian Journal of Fuzzy Systems	6	108	4
IEEE Access	5	108	2
Symmetry	7	69	4
Informatica (Netherlands)	6	61	2
Lectures Notes in Networks and Systems	6	34	0
Studies in Fuzziness and Soft Computing	5	21	0
Advances in Intelligent Systems And Computing	5	14	0
Communications in Computer and Information Science	5	4	2

Science Citation Index, Crossref, PubMed, Application Programming Interfaces, and others. To obtain more insightful knowledge in this area, future research should also use a variety of additional bibliometric analysis tools, such as BibExcel, Bibliometrix, CiteSpace, Gephi, HistCite, SciMAT, or PRISMA.

In the future, researchers can enhance or expand this work by incorporating other novel mathematical techniques, such as the generalized circular IFS [72], circular q-rung orthopair FS [73], bipolar single-valued neutrosophic set [74], and ordered weighted averaging operator [75], among others. Based on the linguistic variables of IFS, decision-making techniques such as the analytic hierarchy process, ELECTRE, PROMETHEE, and TOPSIS can also be applied for further study. Moreover, these IFS-based linguistic variables can be used in application areas such as resources policy, marine fuels, game theory, and artificial intelligence.

6. Conclusion

In conclusion, this study performed a bibliometric analysis of literature related to linguistic variables using IFS. The data were sourced from Scopus, and VOSviewer was employed to evaluate the structure, conceptual evolution, and trends. This analysis included 329 documents published between 2002 and 2024, focusing on publication trends, keywords, and productive authors and cited sources. The aim is to provide insights for researchers and practitioners, highlight significant documents, and suggest future research directions. Additionally, this study includes cluster analysis based on keywords and words in titles and abstracts. This technique enhances understanding of the structure and evolution within the field of research. The findings provide a comprehensive summary of a bibliometric examination of the literature on linguistic variables using IFS. In addition to aiding academics, policymakers, and individuals in understanding linguistic variables based on IFS trends, this study also identifies prospective areas of future study. Ultimately, this study presents a comprehensive overview of the research field and aims to highlight its importance and growth within fuzzy investigation.

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Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data available on request from the corresponding author upon reasonable request.

Author Contribution Statement

Nuraini Rahim: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Binyamin Yusoff:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. **Lazim Abdullah:** Conceptualization, Methodology, Validation, Writing – review & editing, Supervision, Project administration. **José Maria Merigó:** Validation, Writing – review & editing.

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