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SCIENTOMETRIC AND TEXT-MINING ANALYSIS OF RESEARCH TRENDS IN $f(Q)$ GRAVITY AND COSMOLOGY

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Abstract. This review presents a scientometric and text-mining analysis of publications related to $f(Q)$ gravity, dark energy, and cosmology based on literature indexed in the Scopus database from 2021 to 2023. Using tools such as VOSviewer and Biblioshiny, this study identified influential publications, prominent authors, recurring keywords, and emerging research trends. Co-occurrence analysis revealed that topics such as non-metricity, wormholes, cosmic acceleration, and observational constraints dominate the current research landscape. Citation network mapping and thematic clustering expose the evolution of dominant research fronts, including extensions to anisotropic models, wormhole physics, and modified gravity frameworks that incorporate non-commutative geometry and teleparallelism.

The results showed an exponential increase in publication numbers, indicating a proliferating interest with more academic involvement in the field. The analysis maps the relationship between fundamental theoretical advancements and the observational datasets, like Pantheon and BAO, representing a growing intersection between data-driven science and theoretical cosmology. The study emphasizes research contributions across the globe. In short, this scientometric analysis provides a thorough overview of how f(Q) gravity is configuring modern research in cosmology and astrophysics.

Key words: Modified Gravity–General Relativity–Dark Energy–Quantum Gravity–Bibliometric Analysis.

1. INTRODUCTION

Modified theories of gravity, especially f(Q) gravity (Solanki *et al.*, 2021; Hassan *et al.*, 2021; Solanki *et al.*, 2022; Koussour *et al.*, 2022; Mhamdi *et al.*, 2024; Sharif *et al.*, 2025), are becoming more significant in cosmological studies. Application of scientometric methods to it can be helpful to have structured and valuable insights of the field's historical development with the current research trajectories. In recent years, modified gravity has drawn significant interest as scientists are working to get the and understand answers of deep cosmological questions. Scientists are working to get the answers corresponding to the universe's accelerated expansion and the mystery of the nature of dark energy (Koussour *et al.*, 2022a; Hanin *et al.*, 2023; Myrzakulov *et al.*, 2023; Oliveros *et al.*, 2024; Gadbail *et al.*, 2024; Nojiri *et al.*, 2024; Ghosh *et al.*, 2024). The f(Q) gravity (Oliveros *et al.*, 2024; Koussour *et al.*, 2023; Ghosh *et al.*, 2024) builds on the symmetric teleparallel (Sarmah *et al.*, 2024; Jensko *et al.*, 2025) version of general relativity, has emerged as a particularly promising framework among many alternatives. It introduces non-metricity as the core geometric quantity that provides insightful direction for future research in cosmology. Scientometric analysis provides an effective way to track the progress of f(Q) gravity since the interest in it continues to grow. The analysis of publication patterns, citation data, and emerging themes provides more insights into understanding the intellectual structure of the field. This review gives a meaningful picture of how f(Q) gravity (Shaikh *et al.*, 2023; Rana *et al.*, 20214; Ayyoub *et al.*, 2024; Mohanty *et al.*, 2024; Ghosh *et al.*, 2024) research developed with time. It also highlights the key contributions, present research direction, and major topics that are influencing the field today. In recent years, scientist has revealed the accelerated cosmic expansion that results in more attention on modified gravity approaches. Among various modified gravity theories, f(Q) gravity (Bhar *et al.*, 2024; Dimakis *et al.*, 2025) has drawn attention. It is based on the idea of nonmetricity, rather than the usual concept of curvature and torsion. This theory offers an alternative sight to look at how the universe evolves, without invoking hypothetical elements such as dark energy or dark matter. Application of f(Q) gravity have been investigated for the various cosmological models that includes standard flat FLRW background (Koussour *et al.*, 2022a; Hanin *et al.*, 2023), Bianchi type-I geometries (Hanin *et al.*, 2023; Koussour *et al.*, 2022,b, 2023, 2024), and other anisotropic backgrounds. The key cosmological indicators like deceleration parameter (Sahoo *et al.*, 2022; Gadbail *et al.*, 2022), the equation of state (Gadbail *et al.*, 2022), and the energy conditions (Solanki *et al.*, 2022; Jan *et al.*, 2023; Pradhan *et al.*, 2024; Mustafa *et al.*, 2024; Paul *et al.*, 2025) have been studied. Researchers use various advanced methods for the study such as phase space analysis, statefinder diagnostics (Solanki *et al.*, 2022), and Monte Carlo simulations to understand stability and dynamics. Beyond cosmology, F(Q) gravity also plays a significant role in astrophysics. The research conducted by Sahoo P.K., Mustafa G., Mandal S., Hassan Z. have expanded the framework to explore charged wormhole solutions (Hassan *et al.*, 2021; Sharma *et al.*, 2022; Mustafa *et al.*, 2022; Mishra *et al.*, 2023; Pradhan *et al.*, 2024; Sokoliuk *et al.*, 2022), quintessence fields (Mandal *et al.*, 2022; Myrzakulov *et al.*, 2023; Sokoliuk *et al.*, 2024), and Tolman-Oppenheimer-Volkoff equations, therby enriching the understanding of relativistic astrophysics. To validate these models, observational datasets like Pantheon (Mandal *et al.*, 2022; Solanki *et al.*, 2022), Pantheon+SHOES (Narawade *et al.*, 2023), BAO (Solanki *et al.*, 2021), Hubble data (Solanki *et al.*, 2021; Mandal *et al.*, 2022;

Solanki *et al.*, 2022; Sahoo *et al.*, 2022; Narawade *et al.*, 2023; Myrzakulov *et al.*, 2023; Koussour *et al.*, 2024; El Ouardi *et al.*, 2025), and cosmic chronometers (Gadbail *et al.*, 2022) have been employed by the researchers. The different methods, like genetic algorithms, reconstruction methods, and observational fittings, are applied to estimate cosmological parameters (Myrzakulov *et al.*, 2023) and determine the model viability. The recent development also combines f(Q) gravity with teleparallelism concepts, non-commutative geometry (Mustafa *et al.*, 2022; Sokoliuk *et al.*, 2022), and new forms of gravitational functions, like logarithmic or exponential variations. The application of these techniques helps researchers to identify complex phenomena such as phantom phases (Narawade *et al.*, 2023), bulk viscosity (Solanki *et al.*, 2021; Pradhan *et al.*, 2022; Koussour *et al.*, 2024), and different dark energy (Koussour *et al.*, 2022; Myrzakulov *et al.*, 2022; Koussour *et al.*, 2022, 2023) models, advancing our understanding related to the universe's evolution and composition. Despite the expanding body of literature, there is a notable lack of scientometric or bibliometric studies in this area. To address this gap, we present a scientometric analysis of 58 articles published between 2021 and 2025, all centered on f(Q) gravity in cosmology and astrophysics. Utilizing text-mining techniques, we mapped current research trends, identified high-impact contributors (Sahoo P.K., Koussour M., Shekh S.H.), and frequently studied keywords that include wormholes, dark energy (Gadbail *et al.*, 2023; Maurya *et al.*, 2023; Mussatayeva *et al.*, 2023; Koussour *et al.*, 2023; Hatkar *et al.*, 2024), observational constraints, and non-metricity. We highlighted the global distribution of research efforts. This meta-analysis provides a comprehensive view of how f(Q) gravity is evolving as a frontier in modern cosmology and serves as a valuable resource for both new entrants and seasoned researchers in this field.

2. FUNDAMENTAL FORMULATION OF $f(Q)$ GRAVITY

The $f(Q)$ gravity theory is constructed in the framework of symmetric teleparallel gravity, where gravitational effects are encoded through the non-metricity scalar Q rather than the curvature scalar R in General Relativity (GR). The non-metricity tensor is defined as:

$$Q_{\alpha\mu\nu} = \nabla_\alpha g_{\mu\nu}, \tag{1}$$

where ∇_α denotes the covariant derivative and $g_{\mu\nu}$ is the metric tensor.

The two traces of the non-metricity tensor are:

$$Q_\alpha = Q_\alpha{}^\mu{}_\mu, \qquad \tilde{Q}_\alpha = Q^\mu{}_{\alpha\mu}. \tag{2}$$

The non-metricity scalar Q is constructed as:

$$Q = -\frac{1}{4}Q_{\alpha\mu\nu}Q^{\alpha\mu\nu} + \frac{1}{2}Q_{\alpha\mu\nu}Q^{\mu\alpha\nu} + \frac{1}{4}Q_\alpha Q^\alpha - \frac{1}{2}Q_\alpha\tilde{Q}^\alpha. \tag{3}$$

The action for $f(Q)$ gravity is given by:

$$S = \int d^4x \sqrt{-g} \left[\frac{1}{2} f(Q) + \mathcal{L}_m \right], \tag{4}$$

where $f(Q)$ is a general function of the non-metricity scalar and $\mathcal{L}_m$ is the matter Lagrangian.

Varying the action with respect to the metric yields the field equations:

$$\frac{2}{\sqrt{-g}} \nabla_\alpha \left(\sqrt{-g} f_Q P^\alpha{}_{\mu\nu} \right) + \frac{1}{2} g_{\mu\nu} f(Q) + f_Q \left(P_{\mu\alpha\beta} Q_\nu{}^{\alpha\beta} - 2Q_{\alpha\beta\mu} P^{\alpha\beta}{}_\nu \right) = -T_{\mu\nu}, \tag{5}$$

where $f_Q = df/dQ$, $T_{\mu\nu}$ is the energy-momentum tensor of the matter, and $P^\alpha{}_{\mu\nu}$ is the superpotential defined as:

$$P^\alpha{}_{\mu\nu} = \frac{1}{4} \left(-Q^\alpha{}_{\mu\nu} + 2Q_{(\mu}{}^\alpha{}_{\nu)} + Q^\alpha g_{\mu\nu} - \tilde{Q}^\alpha g_{\mu\nu} - \delta^\alpha_{(\mu} Q_{\nu)} \right). \tag{6}$$

For a spatially flat Friedmann–Lemaître–Robertson–Walker (FLRW) universe, the non-metricity scalar simplifies to:

$$Q = 6H^2, \tag{7}$$

where $H = \dot{a}/a$ is the Hubble parameter. Thus, the modified Friedmann equations in $f(Q)$ gravity become

$$3H^2 = \frac{1}{2f_Q} \left(\rho + \frac{1}{2} f(Q) \right), \tag{8}$$

$$2\dot{H} + 3H^2 = -\frac{1}{2f_Q} \left(p + \frac{1}{2} f(Q) \right), \tag{9}$$

where ρ and p are the energy density and pressure of the matter content of the universe.

3. MATERIALS AND METHODS

Scopus is widely used database as a source of research data. Therefore we have extracted the data from the Scopus database by applying some filters to it.

- We have limited the publication year from 2021 - 2025.
- We have limited the subject area to Physics and Astronomy and Mathematics.
- We have limited the document type to the article only.
- We have limited the language to English.

- We have limited the Keyword to f(q) gravity, f (q) gravity, f (q)-gravity, f(Q) gravity.
- Source type is limited to the journal.
- Publication stage of the article is limited to final.
- And open access is limited to all open access and green.

After applying all these limitation we got a dataset of 58 research articles on $f(Q)$ gravity. As the applied search strategy was relied on specific keywords, we found some of the important articles related to the field had not been extracted in the dataset. We have included those high impact papers in the dataset manually (Jiménez *et al.*, 2020),(D'Ambrosio *et al.*, 2022),(Heisenberg *et al.*, 2024). And as a result we got finally 61 research articles to gain a comprehensive understanding of field's development. A dataset of 58 research articles on $f(Q)$ gravity, all sourced from the Scopus database and published between 2021 and early 2025, is considered. To gain a comprehensive understanding of the field's development, we examined various metadata elements of each publication, including titles, abstracts, authorship details, institutional affiliations, keywords, source journals, and citation counts.

The methodological framework used in this review has three primary components.

- We monitor publication trends over a defined period to evaluate the growth and momentum of research activity in $f(Q)$ gravity.
- Identifying leading journals and highly cited papers to recognize the platforms and contributions that have had the greatest influence.
- Performing keyword analysis to find recurring concepts and find out the central research themes and evolving directions within the literature.

3.1. SCIENTOMETRICS AND TEXT-MINING

Scientometric analysis offers a powerful lens through which we can explore how research on f(Q) gravity-an increasingly influential branch of modified gravity theories-is growing and spreading within the scientific community. Using data sourced from Scopus, this study draws on rich bibliographic details, including publication titles, author names, publication years, journal sources, and access status. These elements form the backbone of the analysis, allowing us to map out the field by identifying leading researchers, popular publication platforms, and evolving trends over time. Early findings show a steady stream of publications from 2021 to 2022, with researchers like Sahoo P.K., Hassan Z., and Mustafa G. frequently appearing—pointing to the formation of focused research groups. Journals such as Physics of the Dark Universe, Symmetry, and Annals of Physics emerge as key publication venues, playing a central role in distributing new findings on f(Q) gravity. Notably, the presence of Open Access articles suggests a strong emphasis on making research widely accessible. By applying scientometric tools-such as tracking publication volume and co-authorship links-this study offers a clear picture of how research in this area is taking shape. It not only sheds light on scientific output but also reveals the networks, influencers, and potential directions that may guide future investigations.

3.2. SOFTWARE

VOSviewer, a Java-based tool, was developed by the researchers at Leiden University in the Netherlands. In this study, we employed VOSviewer for scientometric mapping and text analysis. With the use of VOSviewer, it is easy to visualise and understand the complex bibliographic data more easily. It provides the bibliographic details such as titles, abstracts, and keywords, and identifies recurring co-occurrences of terms from the scientific publications. VOSviewer generates visual maps that illustrate the underlying structure and thematic focus of a research domain. The advantage of VOSviewer is that it discovers different kinds of bibliographic relationships, including co-authorship networks, co-citation patterns, bibliographic coupling, and keyword co-occurrences. Such visualisations is helpful for the scholars to identify the prominent authors and track of growing areas of research. VOSviewer uses a graph layout technique developed by its creators, Van Eck and Waltman, to position notes accurately in two-dimensional space. This technique ensures that objects (such as keywords or articles) that are more similar appear closer together on a map. The layout is based on minimizing the weighted sum of the squared distances between all pairs of objects, where the weights reflect the extent to which those objects are related. As a result, visualizations are not only informative but also mathematically grounded, offering a high degree of accuracy in how relationships are portrayed.

3.3. INDICATORS

We focused on the following indicators to apply scientometric and text-mining methods to analyze research trends within the fields of $f(Q)$ gravity and cosmology

3.3.1. Production and chronology

It refers to the total number of articles, books, or other academic works produced by researchers in a particular area. This provides a broad overview of the volume of research output within the field of $f(Q)$ gravity, allowing us to track the growth and evolution of this research area over time.

3.3.2. Topic Analysis

Topic mapping analysis serves as a valuable tool for uncovering the primary and at times, less apparent-topics embedded within the bibliographic records of a research field. By applying a structured and data-driven methodology, this approach enables the identification and visualization of subtle or underrepresented themes that may otherwise remain unnoticed within a large body of academic literature. The resulting visual representations clearly delineated thematic clusters and their interconnections, offering a comprehensive view of the intellectual landscape. This technique has proven particularly effective in text mining and scientometric analyses. Relationships between keywords are established based on their frequency of co-occurrence in published articles; frequent co-occurrence indicates a strong conceptual association. Through this analysis, keywords were grouped into clusters and displayed using the VOSviewer technique, revealing the thematic structure and research trends within the literature.

3.3.3. Citation and highly cited elements

Citation counts are commonly used to gauge how influential a research paper is. By examining how often a study is cited, we can spot the work that has made the biggest impact in the field. In the case of f(Q) gravity, papers with high citation numbers often mark major breakthroughs or serve as key references that many other researchers build upon. This type of analysis is most significant and highly useful for the development of research in this domain.

3.3.4. Keyword Frequency

Keywords in the research papers are more helpful in identifying the topics that are more actively explored. One can also identify the new emerging patterns from the keywords. By studying the distributions of the keyword, we can find the core areas of interest in f(Q) gravity. Such an analysis is useful not only for understanding what is being studied, but also how for revealing how the field is evolving and the possible directions it may take in the future.

3.3.5. Co-citation Analysis

Co-citation analysis provides insights into how research papers are linked through mutual references. The co-citation network generated for this study gives the different clusters of related literature and shows the contribution of prominent researchers in the field. For f(Q) gravity, the co-citation network shows the relationship between various research topics and how academic influence circulates among them. Our study finds the apparent rise in publications on f(Q) gravity, with a core set of high-impact papers driving the field forward. From the keyword analysis, we can observe that areas like cosmology and dark energy dominate current investigations. The co-citation mapping confirms the importance of foundational studies and influential scholars whose work extends to shap the evolution of this domain.

3.3.6. Overlay Visualizations

Overley visualization provides another useful angle to the researcher by adding dimensions like publication year, which enhances citation studies. It is useful for researchers to track the progression and transformation of both research areas and collaboration networks. Overley visualisation assists in detecting new and emerging topics, which makes it an important component of scientometric research. Overlay visualization helps to draw insights from the complex research patterns. Vosviewer is used to create a detailed map that shows connections between topics and authors. These maps include the extra data, such as the time of paper publication and the number of times it gets cited. This offers a clear and deeper understanding of the field.

3.4. DATA ACQUISITION

3.4.1. Source of data

Web of Science (WoS) and Scopus are the two widely used databases as a source of research data. For this review, the data is taken from Scopus, selected for its wide coverage, advanced analytical tools, and interdisciplinary relevance. Scopus being the largest repository of peer-reviewed literature , it offers access to journal articles, books and conference proceedings. The combination of both open-access and subscription content adds more value to Scopus for its role as the best source for bibliometric and scientometric research. The availability of all these special features in the Scopus database helps to draw a well-rounded and more detailed study of research trends.

3.4.2. Collected Data

For the study, the dataset was collected using keyword searches which included topics like f(Q) gravity, modified gravity theories, and cosmological modelling, ranging from the year 2021 to 2025. To obtain the most relevant and meaningful data, the search was carefully conducted, keeping in mind that it should not contain any unrelated or irrelevant data. For further refinement of the results, filters were applied related to the subject area, the document type was restricted to article, and the language is to English only. The publication stage for the data collection was final, and all were from all open-access green. As a result of all this process, a total of 58 documents were obtained, which were then used to identify current research trends and progress in the field. The bibliographic information includes titles, author names, their affiliations, publication year, journal name, number of citations, document type, relevant keywords, and citations. This structured dataset is then used for the bibliometric analysis, with the help of which publication trends is observed, the influential authors and institutions are identified. The information related to citations and co-citation is collected, which provides valuable findings of the areas of interest within f(Q) gravity and cosmology.

4. RESULTS AND DISCUSSION

4.1. OUTPUT AND CHRONOLOGICAL ANALYSIS

Figure 1 shows the yearwise growth patterns for the domain F(Q) gravity and cosmology from 2021 to 2025, for the data collected from Scopus database. The publication output illustrates a varying but notable interest in the field. It shows that the number of publication for the year 2021 was comparatively low, as only 3 documents were recorded. However, this number increased to a significant number for 2022, indicating 18 publications for in the year, which shows growing scholarly attention for the topic.

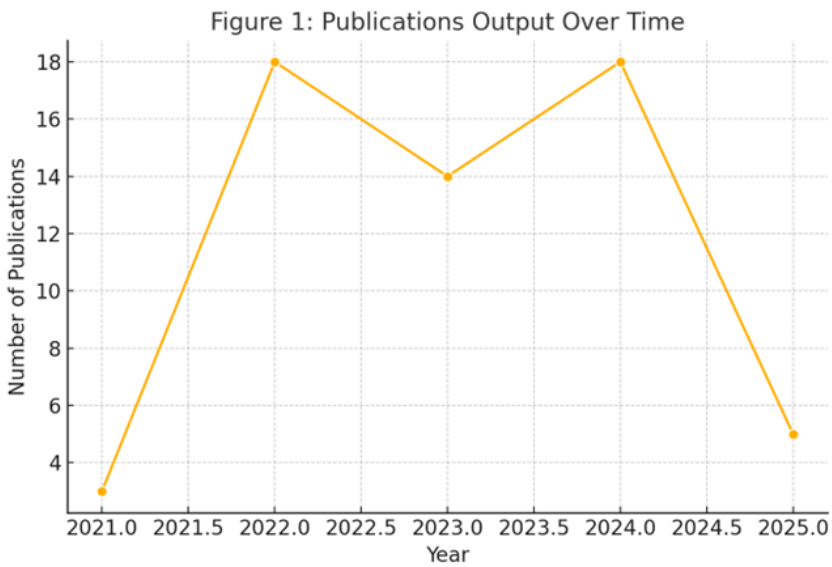

Fig. 1 – Publication Output Over Time.

A slight decline occurred in 2023, with 14 publications, suggesting a brief sta-

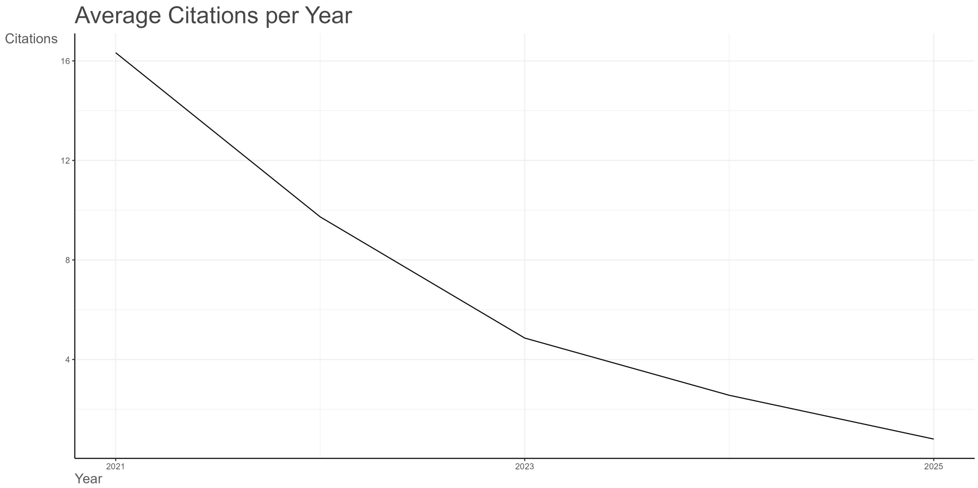

Fig. 2 – Citation per year.

bilization or shift in the research focus. Interestingly, the output rebounded to match the previous peak in 2024 with another 18 publications, reflecting the renewed momentum in the research community. In 2025, however, the number dropped sharply to five, which may be attributed to the partial nature of data collection for the ongoing year.

Overall, the trend demonstrates a significant increase in research activities related to $f(Q)$ gravity and its cosmological applications during the observed period. This upward trajectory, particularly between 2021 and 2024, highlights the emerging relevance of and growing academic engagement with modified gravity theories in addressing fundamental cosmological questions.

Table 1 presents the top 15 most frequently occurring author keywords in the Scopus dataset, which reflect the major themes and research directions within the domains of $f(Q)$ gravity and cosmology. The keyword “$f(Q)$ gravity” appeared most prominently, with 43 publications explicitly using this term, underscoring the central focus of the reviewed literature.

Closely associated terms such as “Dark energy” and “$f(Q)$ gravity” each appeared 9 times, although the latter may reflect variations in keyword formatting rather than distinct topics. Similarly, “dark energy” and “energy conditions” (with their alternate capitalizations) appeared 6 times each, highlighting their recurring importance in theoretical modeling and cosmological analysis. The presence of both upper and lower case variants suggests a need for the standardization of keyword usage during metadata extraction and analysis.

Additional frequently occurring terms include “cosmology,” “Hubble data,” and “Cosmology,” each pointing to observational and theoretical aspects of the uni-

Table 1

Top 15 most productive Scopus categories based on author keywords.

Category	No. of publications
f(Q) gravity	43
Dark energy	9
f (Q) gravity	9
dark energy	6
energy conditions	6
Energy conditions	6
cosmology	4
Hubble data	4
Cosmology	3
deceleration parameter	3
EoS parameter	3
observational constraints	3
Bianchi type-I Universe	3
bulk viscosity	3
Bulk viscosity	2

verse's evolution. Keywords such as "deceleration parameter," "EoS parameter," "observational constraints," and "Bianchi type-I Universe" further demonstrate the field's focus on the dynamical behavior and geometrical modeling of the universe under modified gravity scenarios.

Interestingly, "bulk viscosity" and "Bulk viscosity" are also among the top terms, reflecting the emerging interest in the thermodynamic properties of cosmological fluids within the framework of $f(Q)$ gravity.

Overall, the keyword distribution reinforces that the literature not only centers on $f(Q)$ gravity itself but also frequently integrates broader cosmological parameters and observational concepts, indicating an interdisciplinary and evolving research landscape.

Figure 3 illustrates scientific production by country, as visualized using Biblioshiny, the graphical interface of the Bibliometrix package in R. This map highlights the global distribution of publications, with darker shading representing a higher number of scientific outputs. Among all the countries, India has the highest number of publications (96), followed by Morocco, China, Pakistan, and Kazakhstan, each contributing significantly to the research landscape. Countries such as Chile, South Africa, Ukraine, and Malaysia have also shown notable research activities.

This geographical visualization not only emphasizes regional research strengths, but also helps identify active contributors and emerging regions in the field. It provides valuable insights into how research efforts are distributed globally and supports a better understanding of international trends in scientific output.

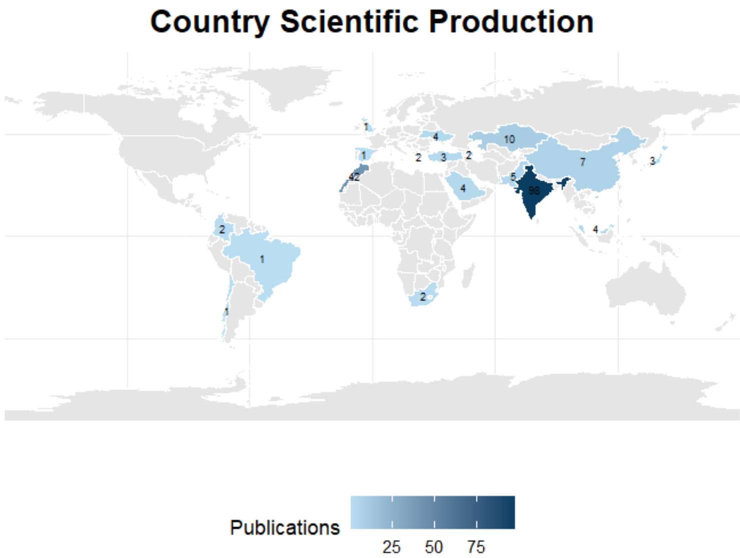

Fig. 3 – Publication Output Over Time.

Figure 4 shows a map of international research collaboration based on the co-authorship between countries. This map was created using VOSviewer, a tool designed to visualize scientific networks. Each circle represents a country, and the lines between them show how often researchers from these countries have worked together. Thicker lines shows stronger collaboration.

India emerges as a central country in the collaboration network, maintaining strong connections with countries like China, South Africa, Saudi Arabia, and Kazakhstan. The Colors on the map denote the average publication year for the collaboration. Darker colors shows older collaborations, while lighter colors shows more recent collaborations.

The visualisation helps us to understand how researchers around the world are working together and indicating that the collaboration is growing over time. The image was created using the data processed by VOSviewer.

4.2. TOPIC ANALYSIS

We applied VOSviewer to carry out topic analysis through schematic mapping, which helps in finding the principal theme within the study of modified gravity and cosmology. In the Scopus database, 129 relevant keywords were identified in the selected literature. These keywords were organized into clusters based on how frequently they appeared in the same publications. Terms that co-occur more often are grouped closely, and the size of each circle represents the frequency with which a

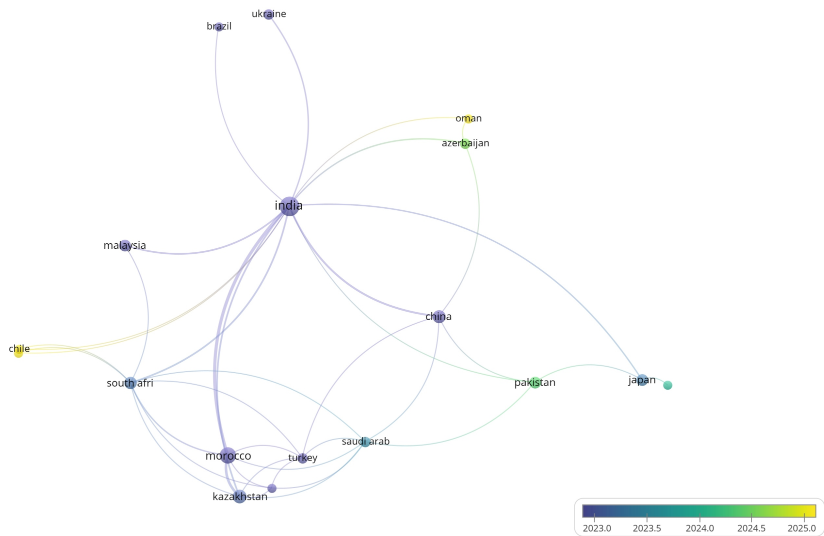

Fig. 4 – Map of co-authorship by country.

keyword appears.

While clustering was performed automatically by the software, we actively contributed to interpreting the map to better understand the key topics and research directions within this field. This allowed for a clearer view of the main focus areas and how they were interconnected.

The analysis included insights from 58 research papers and revealed several dominant topics. Notably, "f(Q) gravity" stands out as a central theme, closely linked with other important concepts such as "dark energy," "cosmology," "energy conditions," "dynamical system analysis," and "black holes." These clusters demonstrate the way researchers explore different theories of gravity and their significance to cosmic evolution, acceleration, and various astrophysical phenomena.

The thematic clustering shown in the following figure identifies '$f(Q)$ gravity' as the dominant topic. Other common themes included dark energy, energy conditions, and cosmology. This highlights the focus on alternative gravity theories and their cosmological implications.

4.3. TOPIC VARIATION OVER TIME

Figure 6 presents the mapping and visualization of scientific publications by country overlaid with the average publication year. This map was generated using VOSviewer to analyze how international research collaborations have evolved over time. Each node on the map represents a country, and the size of the circle indicates

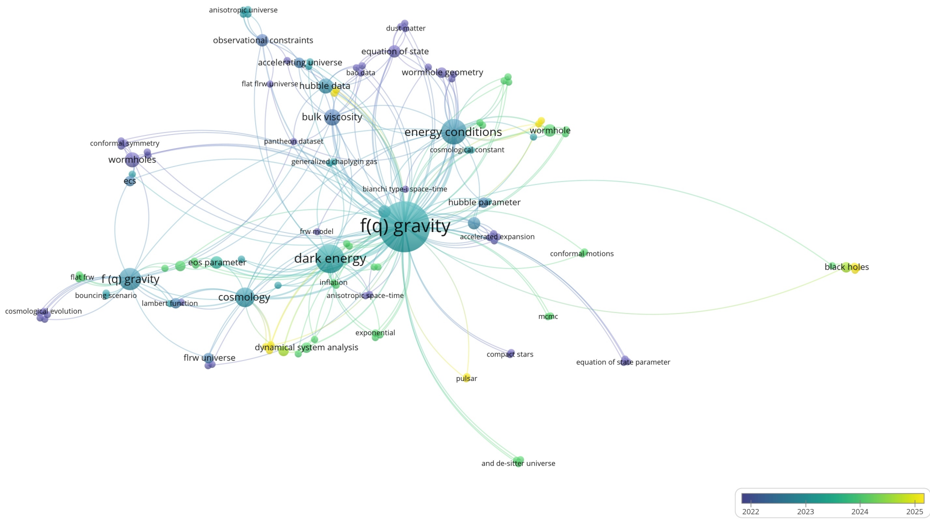

Fig. 5 – Map Of Topics (co-occurrence of keywords.)

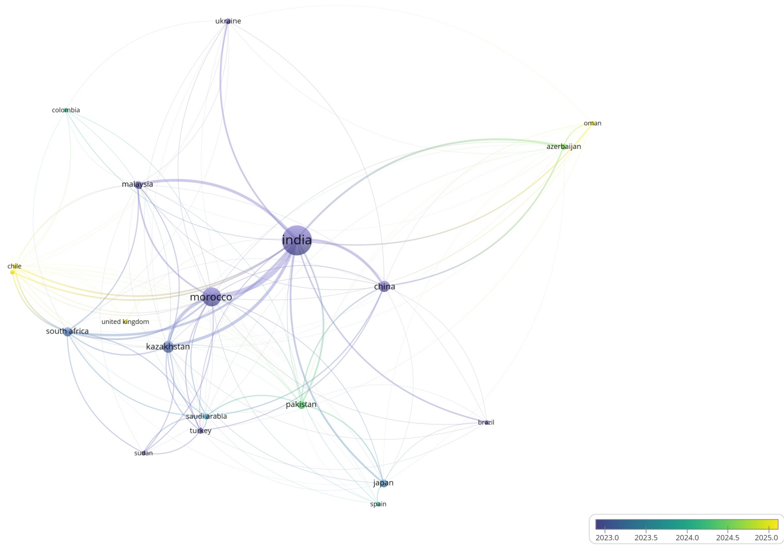

Fig. 6 – Mapping and visualization of the publications by country overlaid with the average publication year.

the volume of publications associated with that country. The lines between countries reflect co-authorship links, with thicker lines representing stronger collaborations.

The color gradient, ranging from dark blue to yellow, shows the average year of publication, where darker tones indicate earlier research activity, and lighter tones represent more recent contributions. India appears to be a central hub in this network, showing strong and ongoing collaboration with countries such as Morocco, China, Kazakhstan, and South Africa. Meanwhile, countries such as Chile, Oman, and Azerbaijan show more recent entry into collaborative research, as suggested by their lighter colors.

This visualization offers insight into the temporal dimension of scientific collaboration, helping to identify both long-standing partnerships and emerging contributors in the research landscape.

4.4. CITATION AND HIGHLY CITED ELEMENTS

Figure 7 presents a visualization of the citation patterns and highly cited keywords generated using VOSviewer. This map highlights the most influential topics within the reviewed literature based on their citation frequency and temporal relevance. The size of each node represents the number of citations associated with a particular term, whereas the color gradient (from blue to yellow) reflects the average year of citation, with more recent citations shown in yellow.

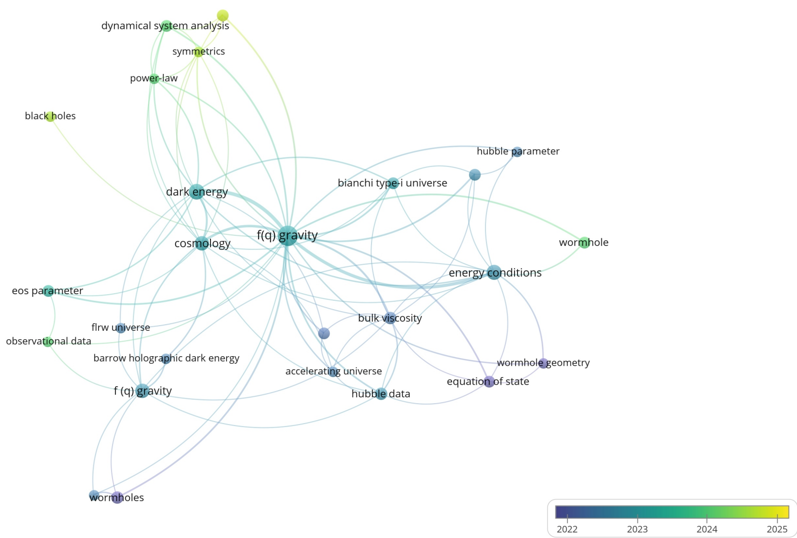

Fig. 7 – Citation and highly cited elements.

Table 2

Top 10 Most Cited Sources.

Rank	Source Title	Citations
1	Physics of the Dark Universe	408
2	Annals of Physics	151
3	Journal of High Energy Astrophysics	119
4	fortschritte der physik	106
5	symmetry	91
6	International journal of geometric methods in modern physics	61
7	Chinesejournalof Physics	49
8	physics letters,section b: nuclear elementary particle and high-energy physics	49
9	Universe	43
10	Physics(switzerland)	39

The centrality of "f(Q) gravity" confirms its role as a core research theme, while other highly cited terms such as "dark energy", "dynamical system analysis", and "wormholes" indicate the major subtopics that have attracted significant scholarly attention. Terms colored in green to yellow, such as "dynamical system analysis" and "black holes", suggest growing or continued relevance in recent years.

This analysis helps identify not only the foundational concepts within the domain but also the evolving focus areas that are driving current research.

4.4.1. Citation by Source

'Physics of the Dark Universe' emerged as the most cited journal, followed by 'Annals of Physics' and 'Journal of High Energy Astrophysics.'

4.4.2. Most Cited Publications

The the most cited paper was "Cosmology in $f(Q)$ Geometry" which emphasized the importance of modified gravity in cosmology. The most cited paper was "Traversable Wormhole Geometries in $f(Q)$ Gravity," which emphasized the importance of wormhole and modified gravity studies.

4.5. CO-CITATION ANALYSIS

4.5.1. Co-citation by Author

The leading co-cited authors are Sahoo, p.k., Koussour M., Bennai,m., and Mandal S., indicating their pivotal roles in advancing the field.

Figure 9 presents a co-authorship network generated using VOSviewer, highlighting the collaborations among researchers in the field. Each node represents an author, with the node size indicating the publication count and connecting lines showing co-authorship links. The color gradient reflects the average year of publication.

Table 3

Top 10 Co-cited Publications.

Rank	Title	Citations
1	Cosmology in $f(Q)$ Geometry (Jiménez *et al.*, 2020)	475
2	Black holes in $f(Q)$ Gravity (D'Ambrosio *et al.*, 2022)	183
3	Review on $f(Q)$ Gravity (Heisenberg *et al.*, 2024)	147
4	Traversable Wormhole Geometries in $f(Q)$ Gravity	103
5	Cosmic acceleration with bulk viscosity in modified $f(Q)$ gravity	95
6	Anisotropic nature of space–time in $f(Q)$ gravity	82
7	Complete dark energy scenario in $f(Q)$ gravity	65
8	Cosmic acceleration and energy conditions in symmetric teleparallel gravity	65
9	Traversable wormhole inspired by non-commutative geometry in $f(Q)$ gravity	57
10	A study of anisotropic spheres in $f(Q)$ gravity framework	50
11	Thermodynamical aspects of Bianchi type-I Universe in $f(Q)$ gravity	49
12	Reconstruction of ΛCDM universe in $f(Q)$ gravity	48
13	Wormhole solutions in symmetric teleparallel gravity	47

Table 4

Top 10 Co-cited Authors.

Rank	Author	co-cited count
1	Koussour, M.	383
2	Bennai, M.	313
3	Sheikh, S.H.	295
4	Myrzakulov, N.	77
5	Godbail, Gaurav N.	101
6	Hassan Ninnat	296
7	Mandal, Sanjay	303
8	Sahoo, P.K.	679
9	Solanki,Raja.	232

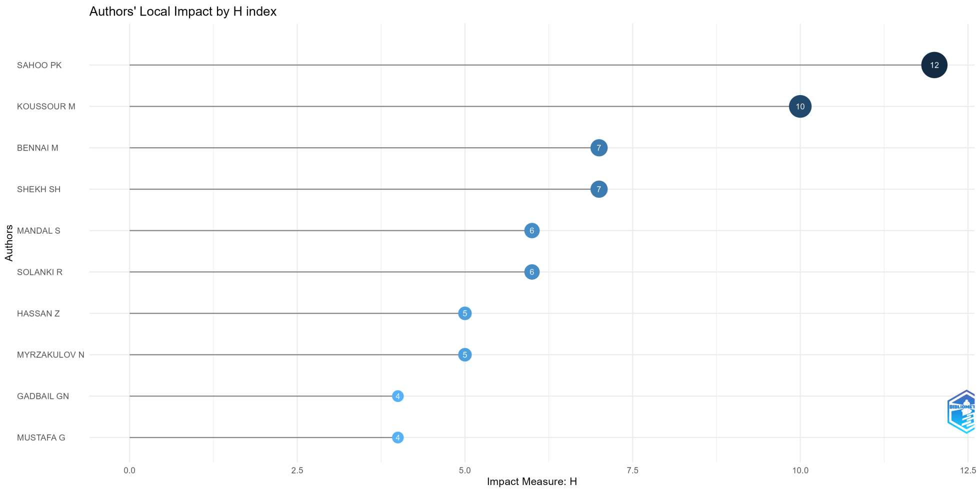

Fig. 8 – Authors Impact.

Prominent clusters, such as those involving Sahoo P.K. and Koussour M., suggest active collaborative networks. This analysis helps to identify key contributors and collaboration patterns within the research area.

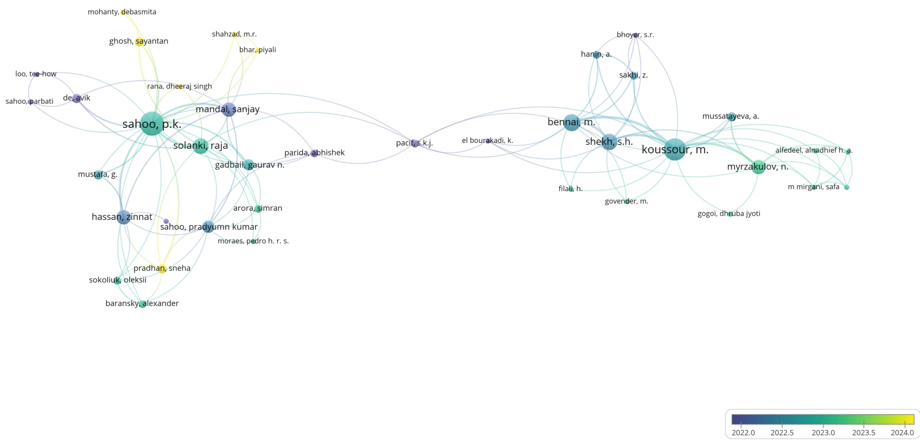

Fig. 9 – Co-Authorship by author.

5. CONCLUSION

This review provides a comprehensive overview of recent research developments in the chosen field, highlighting key themes, influential contributors, and collaborative trends. Using bibliometric tools, such as VOSviewer and Biblioshiny, we mapped topic evolution, citation patterns, and co-authorship networks to gain deeper insight into the structure and growth of the research landscape. The analysis revealed increasing interest and active collaboration among scholars, with particular focus areas emerging as central to ongoing discussions. By identifying the most frequently explored topics and key contributors, this study serves as a helpful resource for researchers seeking to understand the current directions and potential gaps in the literature. Future studies may benefit from further interdisciplinary collaboration and the continued exploration of underrepresented themes.

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