Collaborative Analysis of Soil Nailing Research

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Abstract

This research study focuses on the growth and development of soil nailing research in terms of publication output reflected in the Scopus database from 2001 to 2020. A total of 836 documents were published in this area. The average number of documents published per year was 41.8, and the highest number of documents, 78 (9.33%), was published in 2014. Out of total documents, 503 (60.17%) documents received 4601 citations during the study period. Simultaneously, the average degree of collaboration and average collaboration coefficient are 0.86 and 0.56, respectively. The most prolific author is Yin, J.H. from Hong Kong, who contributed 24 documents. The most contributory source is "Yantu Gongcheng Xuebao Chinese Journal of Geotechnical Engineering," with 76 (22.82%) documents. Among the institutions, Tongji University of China topped the list with 36 documents. China was the most productive country in soil nailing research, with 406 documents. The scientists' most preferred subject was Earth and Planetary Sciences, with 531 (39.3%) documents. The high-frequency keyword co-occurrences were soil nailing (364 occurrences) and excavation (181 occurrences). This study explores the research productivity of soil nailing concerning future growth.

Keywords**:** Scientometric analysis, Soil Nailing, Research productivity, Authorship pattern, Co-authorship analysis, Visualisation

0. Introduction

The modern era is the era of construction. In this time, more and more construction work is being done, for which new technology and new methods started developing. Soil nailing is one of those technologies which make construction work in water, bridges, and others possible. Soil nailing is a technique for stabilizing the ground, and it may be helpful to increasing the structure's stability and lowering the risk of failure (Ayazi, Tangri, & Jalota, 2020). This approach differs from the traditional (pre-1960) tunneling method, which used a stiff lining to prevent soil deformation and was exposed to total ground pressure loading (Ortigao and Palmeira, 2004).

1. Concept of Soil Nailing

The soil nailing technique was derived from the New Austrian Tunneling Method, which was created in the late 1960s and consists of a flexible liner that prevents deformation of the soil around the excavation and is reinforced with bolts or nails (Ortigao, Palmyra, & Ziralis, 1995; Ayazzi et al., 2020; Rabsewicz, 1964a, 1964b, 1965). It involves reinforcing the ground at the construction site using rods or structural elements, known as nails, which can be driven or installed into grouted drill holes. The nails are put horizontally during excavation to resist tensile forces and allow the walls to support the soil with nails (Schlosser & Unterreiner, 1991).

In 1972, the first round of this technology was used in France at Versailles to maintain a rail track cut (Rabejac & Toudic, 1974). Soil nailing techniques became popular in France and other European countries after the completion of the Versailles project. In 1975, Germany was the first country to employ soil nail walls. The first important research program on floor nail walls was done at the universities of Karlsruhe and Bauer in Germany (Stocker, Korber, Gassler, & Gudehus, 1979). One of the first soil management applications announced in the United States in 1976 was a 13.7 m (45 ft.) deep foundation in dense mud lake sand to expand Good Samaritan Hospital in Portland, Oregon. In India, the usage of soil management technology is gradually growing, and the Indian Roads Congress (IRC) has released some highway construction soil nailing rules.

As work advances from top to bottom, the goal of soil nailing is to strengthen or stabilize existing steep slopes and excavations (Budania & Arora, 2016). Soil nails produce their reinforcing action due to soil-nail contact caused by ground displacement, which causes the soil nail to develop tensile pressures. Axial force development, a tension force, is the source of the resistances (Dey, 2015). In soil nailing, the reinforcement is placed horizontally or gently inclined parallel to the path of tensile strain (Dey, 2015; Panigrahi&Dhiman, 2019).

2. Scientometric study

Scientometric is "the study of measuring scientific and technological development" (Chen, McCain, White, & Lin, 2002; Garfield, 1979). This is one of the most important metrics of the research findings (Chitra & Jeyshankar, 2012; Patel, Singh, Singh, & Patel, 2021a). It is quantitative analytics, which is used to estimate and analyse the amount of research in a particular field. The scientometric methodology provides a broad perspective on the philosophy of science, defining the general direction of innovation in a given field over time (Khalaj, Kamali, Costa, & Capela, 2020). The aim of scientometric research is to inform, educate, and expose key stakeholders about the state-of-the-art in a given field, as well as to identify a possible change in approach (Serenko & Jiao, 2012). Academics have long been interested in scientometrics because it helps them better understand their field's distinctiveness and identity (Hassan & Loebbecke, 2017). It is currently being used as a combination of statistical and mathematical tools to reveal historical literature trends, identify current hotspots, and predict future research trends. So far, researchers have used scientometric analysis to uncover quantitative aspects and research trends in the field of soil nailing.

3. Literature review

The number of scientometric studies in the field of science has increased in recent years. Some of them were referred to in this study. Fernandes, Gomes, Monteiro, Dórea, and Bernardi (2021) reviewed soil mercury research from 1991 to 2020. Most soil mercury research has been done in Asia, Europe (Spain, Slovenia, and Italy), and the Americas (the United States and Brazil). Feng et al. (2021) investigated the state of water research in frozen soil with the help of scientists. The most widely used Journal, according to this research, is Cold Regions Science and Technology, which published 103 publications on unfrozen water in frozen soil. Pan, Lv, Dyck, and He (2021) used bibliometric analysis based on data from the Web of Science core collection combined with software tools to demonstrate the evolution of soil nutrient research trends. The findings reveal that between 1992 and 2020, the number of publications produced has expanded dramatically. Kamali et al. (2020) carried out a scientometric analysis of the research on the use of biochar as a soil amendment. Lin, Zhu, Ahmad, and Han (2019) conducted a scientometric analysis of Brownfield research from 1995 to 2017. The focus of the research had switched from soil remediation technologies to sustainable regeneration tactics due to the recent study's findings. Liu, Wu, and Zhao (2019) performed a bibliometric analysis of documents on soil health in the Web of Science Core Collection from 1999 to 2018. The current state of soil health research and development were explored in this study. Mao et al. (2018) evaluated current research in the field of contaminated soil remediation and identified research areas that are trending.

All of the studies mentioned above conducted systematic literature reviews but did not use purely scientometric tools to investigate the evolution and development of soil nailing research. Hence, it is one of the first study which the researchers undertook in this field of soil nailing. This present study is intended to assist scholars all around the world by providing a brief overview of the current state and trends in the field of soil nailing.

4. Objectives of the study

The study deals with the following objectives:

1. To examine the year-wise distribution and general growth of documents with citations;
2. To find out the authorship pattern and collaborative measures (DC, CC, and MCC);
3. To analyses most prolific author; the collaboration of institutions and countries;

4. To examine the forms and subject wise scattering of documents; and
5. To determine the most productive source and occurrence of keywords.

5. Methodology

5.1.Data Source

This study aims to provide a quantitative analysis of global soil nailing research publications from the Scopus Database. Scopus is an abstracting and indexing database with full-text links produced by the Elsevier Co. (Burnham, 2006), one of the world's largest peer-reviewed literature databases (Zyoud, Al-Jabi, &Sweileh, 2014).

5.2.Data Collection

The data was extracted from the Scopus database (http://www.scopus.com), and it covered the years 2001 to 2020. The search keyword was "Soil nailing." The search string used for the study was TITLE-ABS-KEY (soil AND nailing) AND (LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2001)) AND (LIMIT-TO (PUBSTAGE, "Final")) accessed on November 10, 2020. A total of 836 publications data were extracted and imported to the ".csv" file.

5.3.Data analysis

The researcher used MS-excel, Google sheets, and VOSviewer version 1.6.16 to perform analysis and network mapping. The researchers examined key indicators, including year-wise distribution and growth rate of documents, measures of collaborations, the most productive authors, top ten sources, highly productive institutions, form-wise distribution, subject-wise scattering, and top ten funding agencies. Further, the VOSviewer software was used to create a network of co-authorship and co-occurrence indicators. Figure 1 depicts a Step-by-step workflow of the research process.

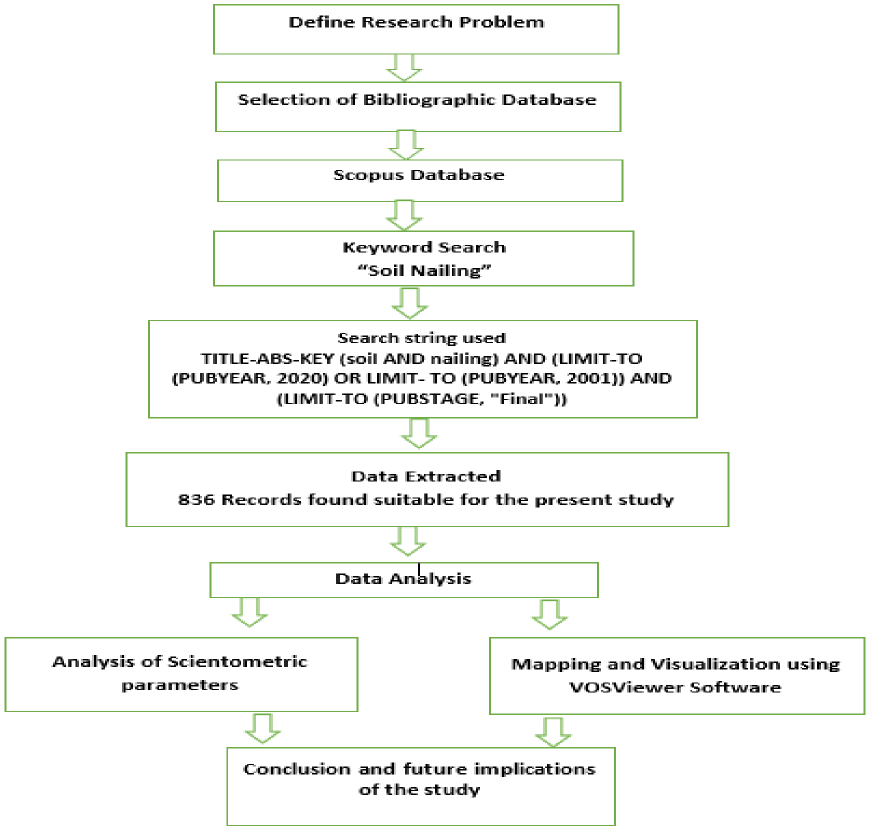

Figure 1: Step-by-step process

6. Results and Discussion

6.1. Year-wise distribution and growth rate of documents

The year-wise distributions and general growth rate of documents (GGRD) with citations are examined in Table 1. A total of 836 documents were found from 2001 to 2020. During the study, the maximum number of documents, 78(9.33%), was published in 2014, while a minimum number of documents was 6(0.72%) in 2001. The frequency of the documents shows continuous fluctuation during the last two decades. In 2015, the document growth rate was less productive (-57.69%), and the growth rate was maximum (150%) in the year 2004. Fluctuations in GGRD are much more, as well as citations. Out of the total 4601 citations, the average citation per document is 6.98, more significant than the total citations per document, i.e., 5.50.

Table 1

Year-wise distribution and growth rate of documents

Year	TD	GGRD	CSD	Citation	CPD
2001	6	-	6	80	13.33
2002	8	33.33	14	102	12.75
2003	10	25.00	24	164	16.40
2004	25	150.00	49	383	15.32
2005	45	80.00	94	383	8.51
2006	40	-11.11	134	223	5.58
2007	35	-12.50	169	191	5.46
2008	37	5.71	206	458	12.38
2009	44	18.92	250	416	9.45
2010	50	13.64	300	305	6.10
2011	70	40.00	370	332	4.74
2012	66	-5.71	436	300	4.55
2013	68	3.03	504	255	3.75
2014	78	14.71	582	244	3.13
2015	33	-57.69	615	157	4.76
2016	42	27.27	657	168	4.00
2017	53	26.19	710	186	3.51
2018	43	-18.87	753	153	3.56
2019	46	6.98	799	79	1.72
2020	37	-19.57	836	22	0.59
Total	836			4601	5.50

Note* TD= Total Documents, GGRD= General Growth Rate of Documents, CSD= Cumulative Sum of Documents, CPD= Citation per Documents

6.2.Measures of collaboration

6.2.1. Degree of collaboration

Degree of Collaboration (DC), which is a proportion of multiple-authored papers, is easy to calculate and interpret as a degree (it ranges from 0 to 1), gives no weight to single-authored papers, and always ranks higher in a discipline (or period) with a higher percentage of multiple-authored papers. DC, on the other hand, makes no distinction between levels of multiple authorship. Subramanyam (1983) proposed a formula for calculating the degree of collaboration (DC). The degree of collaboration can be expressed mathematically as:

$$DC = \frac{Nm}{Ns + Nm}$$

Where,

C = degree of collaboration in a discipline

Nm = number of multi-authored papers in the discipline

Ns = number of single-authored papers in the discipline

The analysis illustrates that the maximum degree of collaboration was 1.00 in 2002, i.e. in this year; there is no single authored publication, while the lowest was 0.40. The average DC is 0.86, which shows that the multi-authored publications are maximum in this field.

6.2.2. Collaboration coefficient

The collaborative coefficient (CC) is a measure of research collaboration that considers both the average number of authors per paper and the proportion of papers with multiple authors. Although it is between 0 and 1, and is 0 for a collection of purely single-authored papers, it is not 1 for a collection of maximally authored papers, which means that every publication in the collection has all of the collection's authors as co-authors.Ajiferuke, Burrell, and Tague (1988) suggested the collaboration coefficient (CC) measured by the formula. It can be mathematically expressed as:

$$CC = 1 - \frac{\sum_{j=1}^{k} \left(\frac{1}{j}\right) f_j}{N}$$

Where,

j = number authors in an article i.e., 1, 2, 3 ……

fj = number of j authored articles

N = total number of articles published in a year, and

A = total number of authors per article

The lowest collaboration coefficient was 0.25 in 2003, while the highest collaboration coefficient was 0.66 in 2016 and 2019. The average CC was 0.56, i.e. it means there is moderate collaboration of co-authors.

6.2.3. Modified collaboration coefficient

The new measure's derivation is nearly identical to that of CC, as described by Ajiferuke et al. Assume that each paper carries a single "credit," which is shared among the authors. Savanur and Srikanth (2010) proposed a formula for calculating the modified collaboration coefficient (MCC). The formula can be mathematically expressed as:

$$MCC = \left(\frac{A}{A-1}\right)\left\{1 - \frac{\sum_{j=1}^{A} \frac{1}{j}(Fj)}{N}\right\}$$

Where, j = number authors in an article i.e. 1, 2, 3 ……

Fj = number of j authored articles

N = total number of articles published in a year, and

A = total number of authors per article.

The lowest modified collaboration coefficient was 0.27 in 2003, while the highest modified collaboration coefficient was 0.74 in 2002. During the study period, average MCC shows the moderate credit for single authors among the authors.

6.3.Most productive authors

Figure 2 illustrates the most productive writers in the study's Soil Nailing discipline. Out of 159 total authors with two or more documents, Yin, J.H. (from Hong Kong) is the most prolific author, contributing 24 (17.78%) documents. Similarly, Zhu, Y.P. (China) came second with 23 (17.04%) research documents, while Yang, M. (China) came third with 15 (11.11%) documents. Figure 2 shows the most prolific authors by the number of contributions. Other authors provide the remaining records, making up 16.25 percent of the total. The graph reveals that most authors are from China and Hong Kong. Furthermore, multiple authorship patterns dominated single authorship patterns.

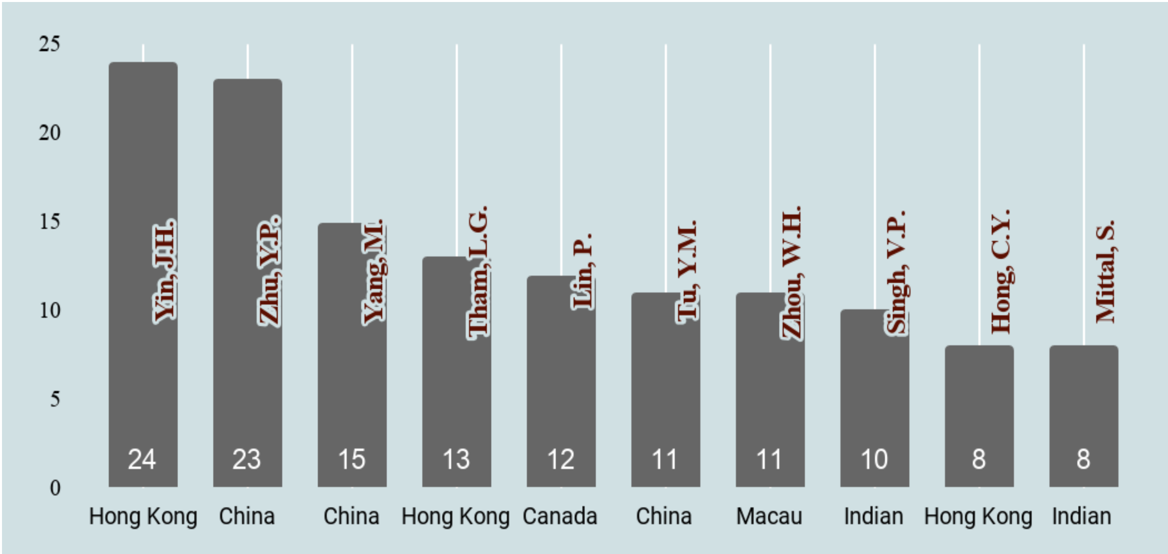

Fig.2. Most Productive Authors

6.4.Top ten soil nailing sources

The top 10 sources that released the most documents in soil nailing research are included in Table 2. In this table, CiteScore, SJR, SNIP, h-index and Quartiles ranking metrics were also used by the researchers, which quantify scientific productivity and scientific impact of journals. The most influential source is 'Yantu Gongcheng Xuebao Chinese Journal of Geotechnical Engineering, which contributed 76 (22.82%) documents, followed by 'Yantu Lixue Rock and Soil Mechanics, which contributed 58 (17.42%) documents, Applied Mechanics and Materials 36 (10.81%), and Geotechnical Special Publication 30 (9.01%). The majority of these sources come from China and the United States.

Table 2

Top ten sources in soil nailing

Source Journal	Documents	Cite Score	SJR	SNIP	h-index	Quartiles
Yantu Gongcheng Xuebao Chinese Journal Of Geotechnical Engineering	76	1.40	0.605	1.047	46	2
Yantu Lixue Rock And Soil Mechanics	58	1.60	0.635	1.032	45	2
Applied Mechanics And Materials	36	0.00	0.112	0	29	-

Geotechnical Special Publication	30	0.50	0.245	0.246	36	-
Journal Of Geotechnical And Geoenvironmental Engineering	27	6.00	2.254	2.397	142	1
Yanshilixue Yu GongchengXuebao Chinese Journal Of Rock Mechanics And Engineering	26	2.00	0.718	1.206	74	2
Advanced Materials Research	25	0.00	0.121	0.181	33	-
Canadian Geotechnical Journal	19	5.70	1.934	2.424	109	1
Computers and Geotechnics	19	6.60	2.217	2.298	89	1
Electronic Journal Of Geotechnical Engineering	17	0.40	0.123	0.204	25	4

Note* Cite Score, SJR and SNIP were calculated as per 2019, h-index and Quartile

6.5.Highly productive institution

Figure 3 shows the highly productive institutions that have collaborated on Soil Nailing research. Out of 159 institutions with two minimum numbers of documents, the Tongji University, China has highly published documents related to soil nailing with 4.31% collaboration of entire documents. The Lanzhou University of Technology, China with 3.83%, Hong Kong Polytechnic University, Hong Kong with 3.71%, Ministry of Education China with 3.47%, and Zhejiang University, China with 2.87% collaboration of total documents. Further, it shows that most of the high-productivity institutions are from China. Therefore, it can be interpreted that Chinese researchers have dominated the Soil Nailing research. These top-listed institutions have approximately one-third collaboration of the total of documents. The remaining institutions have the collaboration of two-third of the total documents.

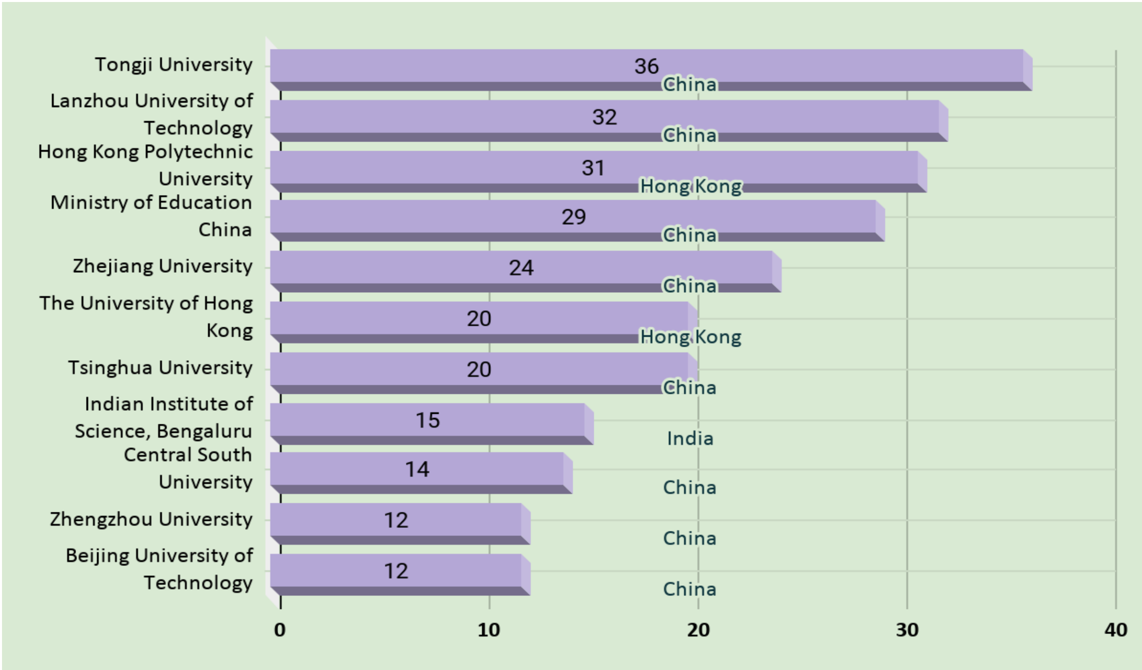

Fig.3. Top Most Institutions with Country

6.6.Country-wise collaboration with network visualisation

Figure 4 shows global network connectivity. To evaluate the data, the researchers set 5 minimum documents and 15 minimum citations per country. Only 20 countries met the criteria. The red color represents Cluster 1, including China, India, Hong Kong, Iran, the US, and the UK. Cluster 2 is made up of Germany, Austria, Sweden, and Finland. Cluster 3 is represented by the blue color and includes Spain and Chile. China topped with 406 (55.31%) articles, more than half of all publications, while India is second topped country with 70 (9.54%). Followed by Hong Kong had 55 (7.49%) articles, and Germany had 20 (2.72%) articles. India is a fast developing country where large numbers of infrastructure projects are under progress i.e. power, mining and civil (road, railway and metro etc.) to cater the basic facilities to the large population in the country. The Indian Roads Congress (IRC) has produced rules with the support of the Indian Institute of Science in Bangalore for the construction of roads and bridges, etc. (Budania & Arora, 2016).

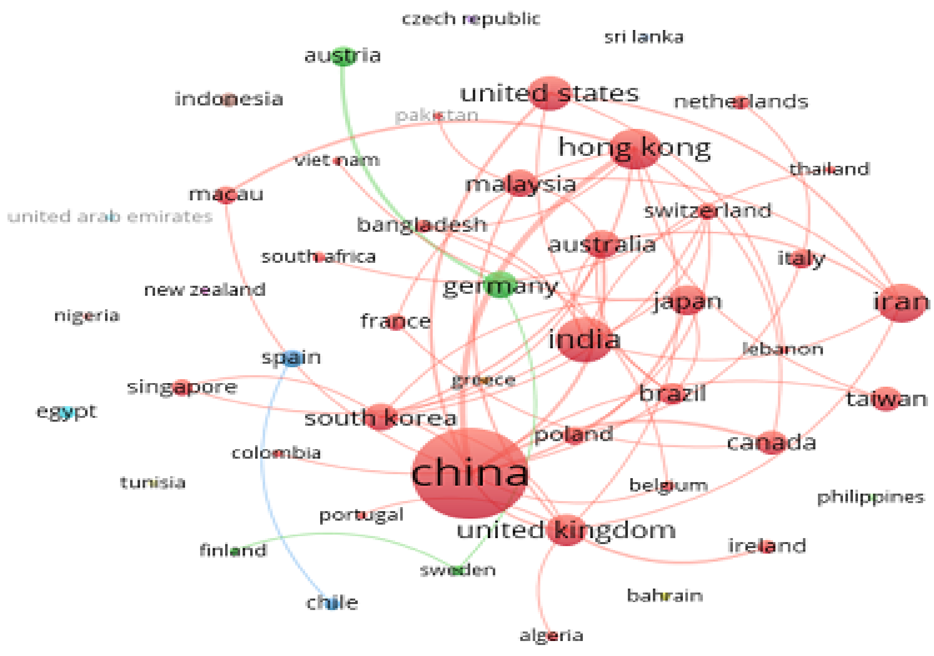

Fig.4. Network visualisation of countries

6.7.Form-wise distribution of publications

Figure 5 represents the forms of publications in soil nailing research. This study has several publications such as articles, conference papers, book chapters, reviews, etc. Among the total number of documents, 563(67.34%) documents are articles, and 239(28.59%) documents are published as Conference Paper. Articles and conference papers are the two most preferred mediums of publication, with a combined percentage of 95.93 percent. The remaining 4.07% of the total documents are other forms like book chapters, reviews, books, and notes. Therefore, it reveals that this research on soil nailing is mainly published in the form of articles.

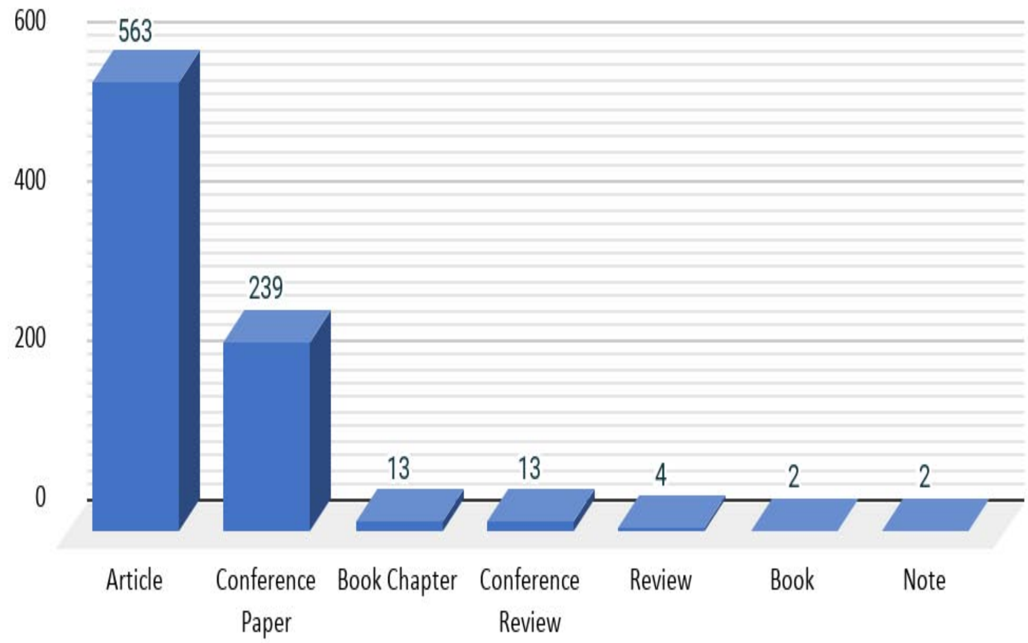

Fig.5. Forms distribution of Publications

6.8.Subject wise scattering of publications

Table 3 indicated that subject-wise research strength with their number of documents as well as percent. Subject-wise distribution shows the association of different subjects/disciplines with soil nailing research. Furthermore, a clear picture of research trends in various disciplines can be obtained. Out of 8 subjects' strengths, the Subject "Earth and Planetary Sciences" has the highest number of research documents of soil nailing, i.e., 531 (39.3%), followed by “engineering” subjects contributing 442 (32.72%) documents. The above two topics have two-thirds of the total research documents of the study period. The remaining six subjects have only approximately one-third of the complete research documents.

Table 3

Subject wise scattering of Publications

Subject area	**Documents (%)**
Earth and Planetary Sciences	531(39.3)

Engineering	442(32.72)
Agricultural and Biological Sciences	152(11.25)
Environmental Science	80(5.92)
Materials Science	43(3.18)
Computer Science	35(2.59)
Physics and Astronomy	22(1.63)
Arts and Humanities	17(1.26)
Multidisciplinary	15(1.11)
Social Sciences	14(1.04)

6.9. Top ten funding agencies

The top funding agencies for soil nailing research acknowledged in published sources are shown in Figure 6. China's National Natural Science Foundation has the highest number of publications, 35 (53.03%), implying that half of the publications are funded, followed by the Natural Sciences and Engineering Research Council of Canada with 10.61% contributions, and the Australian Research Council, National Research Foundation of Korea. The contributions from the other funding agencies for research were less than 5% of overall contributions.

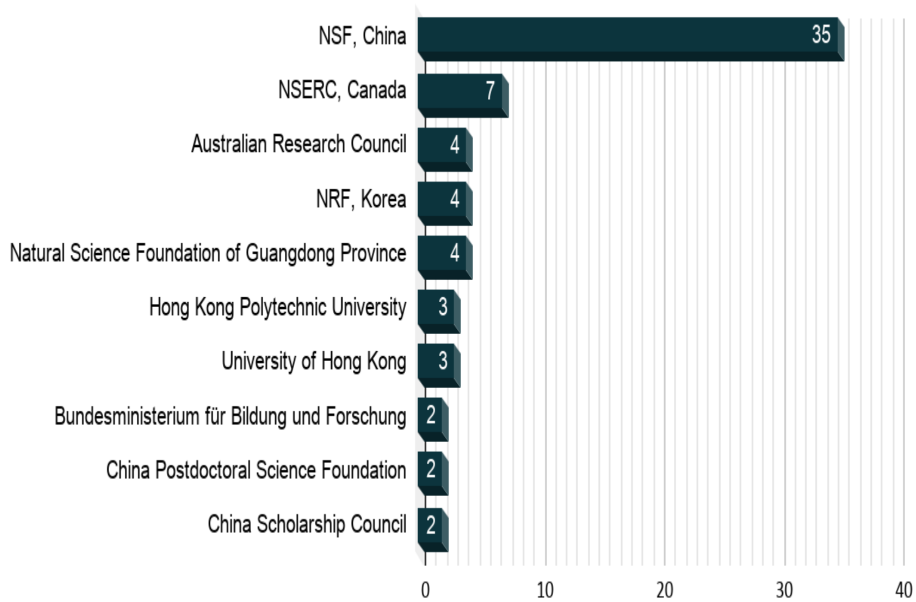

Fig.6. Top ten funding agencies

6.10. Co-authorship analysis of authors

Co-authorship analysis in scientific and technological (S&T) collaborations provides a picture of collaboration patterns between individuals and organisations (Fonseca, Sampaio, Fonseca, & Zicker, 2016). Co-authorship of the authors occurs when more than one author contributes to creating a study, resulting in a higher quality or quantity of scientific output (Acedo, Barroso, Casanueva, & Galan, 2006; Hudson, 1996). The data has 1627 authors. The author minimum was set to 3, resulting in 152 authors in VOSviewer. Figure 7 displays five alternative clusters of authors with a minimum of 10 author sizes represented in different colors. In Cluster 1, a red circle represents 26 authors, such as Tham, I.G. (13 papers), Wang, S. (11 documents), and Yue, Z.Q. (7 documents). Cluster 2 consists of 21 authors, including Yang, M. (16 documents), Zhang, J. (11 documents), Li, X. (7 documents), and others. An 18-authors cluster 3 (blue circle) includes Liu, J. (13 papers), Lin, P. (12 documents), Wu, X. (5 documents). In cluster 4, the yellow circle represents 18 authors, including Zhu, Y.P. (20 papers), Dong, J.H. (10 documents), Zhang, G. (8 documents). Yin, J.H. (22 papers), Zhou, W.H. (10 documents), Su, I.J. (8 documents), and others comprise Cluster 5. Cluster 1 has more co-authors than cluster 2 and other clusters. These clusters show groups of co-authors with respect to their collaborations.

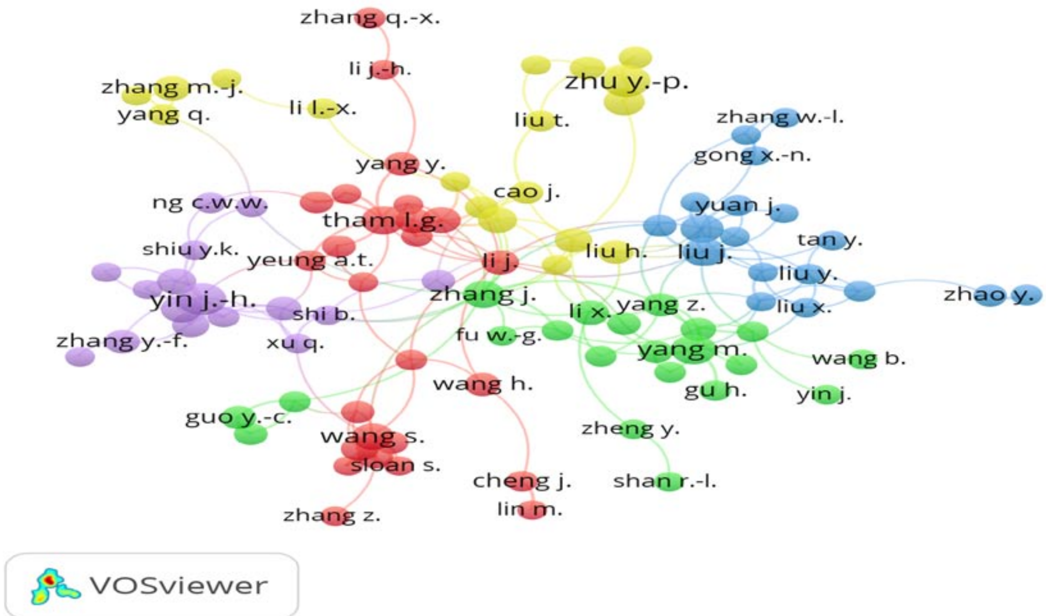

Fig.7.

Co-authorship analysis of authors

6.11. Keywords co-occurrence analysis

Co-occurrence analysis depicts the link between things based on the number of times they appear in the same publication. Co-occurrence analysis not only identifies popular topics and research directions, but it also serves as a significant indicator for tracking changes in scientific fields (Gao, Xing, Dong, & Lin, 2020). It seeks to discover popular study areas and directions (Liu & Mei, 2016; Wang, Xing, Zhu, Dong, & Zhao, 2019). Co-occurring terms are two terms that appear in the same title/abstract or citation (Bornmann, Haunschild, & Hug, 2018). The keyword is a scientific indicator of a research publication's quality (Patel, Singh, Patel, & Singh, 2021b). The database contains 5038 keywords. With a co-occurrence threshold of 5, VOSviewer found 435 terms. In Figure 8, five clusters of keywords with a minimum of 42 keywords each are shown. For example, soil nailing (364 occurrences), slope stability (133 occurrences), and reinforcing (117 occurrences) are found in Cluster 1. For example, soil-nailing (225 occurrences), excavation (181 occurrences), and support (160 occurrences) are all found in Cluster 2. Keywords in Cluster 3 include dirt nails (128), grouting (67), mortar (58), and others. Cluster 4 has 65 keywords, each represented by a yellow circle, such as soils (510), safety factor

(85), and stability (38). Keywords in Cluster 5 include finite element method (112), numerical analysis (43), slope (32), and others.

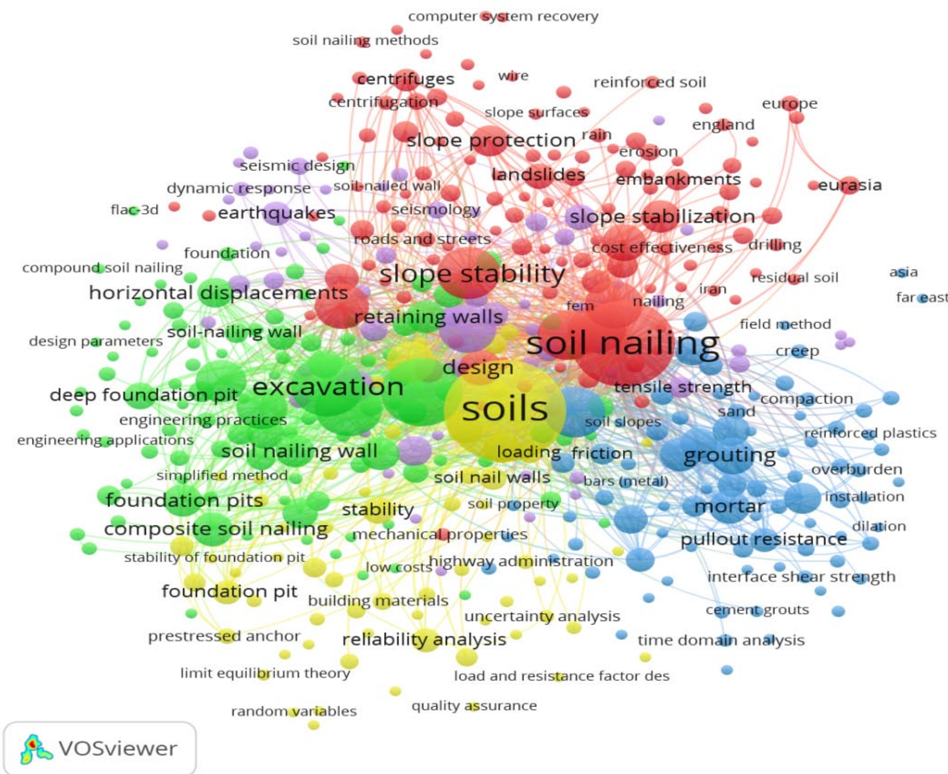

Fig.8. Keywords co-occurrence analysis

7. Conclusion

This study examines the number of scholarly contributions in soil nailing research published in Scopus from 2001 to 2020. 836 papers were chosen for this investigation. The study's average citation per document was 6.98, and multi-author research collaboration was very high. J.H. Yin is the most prolific author, and Tongji University is the most collaborative. Most soil nailing research was done in China (55.31%), and most researchers preferred to publish their findings in journals (67.34%).

The study also found China to be a well-funded country for soil nailing research. These data demonstrate the significance of scientometrics in assessing global soil nailing research trends. Soil nailing stabilizes slopes and excavations by embedding reinforcement into the soil bulk. Several completed projects show that slopes with soil nails are more stable and have fewer minor deformations than slopes without nails. Soil nailing is up to 30% cheaper than other methods for repairing and improving existing slopes. It is also eco-friendly, causing minimal environmental damage. Soil nailing researchers might use this scientometric study as a guide. Future academics would also benefit from more in-depth research in this area.

Acknowledgment

The authors would like to thank Dr. Praveen Gatla, Department of Linguistics, Banaras Hindu University (BHU), Varanasi, for copy-editing. Further, the authors also would like to thank the extensive editorial interventions of the Journal for improving the paper from the guidelines.

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