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A Bibliometric Analysis of WOS Database Publications in the Field of Soil Improvement from 2020 to 2025

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Abstract: This study presents a comprehensive bibliometric analysis of soil improvement research using Web of Science (WOS) data from 2020 to 2025, conducted with VOSviewer software. A total of 6,850 articles were analyzed using the keywords "soil stabilization," "soil improvement," "ground stabilization," and "soil reinforcement." The analysis covered multiple aspects, including citation and publication trends by country, institutional citations, co-authorship networks, keyword co-occurrence, and bibliographic coupling among authors. The results indicate that China leads in publications (1,580) and citations (15,685), followed by India and the United States. Meanwhile, Singapore recorded the highest citation-per-publication ratio (15.6), whereas India had the lowest (8.2), suggesting differences in global research impact despite high publication output. Institutional analysis revealed that Chinese universities dominate the field, while Islamic Azad University (Iran) ranked second, despite Iran not being among the top-ranking countries in overall publication impact. The keyword analysis showed that "geosynthetics" was the most frequently used term, reflecting the increasing prominence of geosynthetic-based soil improvement techniques. Other frequently used keywords included "soil stabilization," "ground improvement," "unconfined compressive strength," and "soil improvement." The study provides valuable insights into global research collaborations, emerging topics, and areas requiring further investigation, contributing to a comprehensive understanding of soil improvement research trends and future directions.

Keywords: Soil Improvement, Bibliometric Analysis, VOSviewer, Citation Analysis, Article Analysis

Öz: Bu çalışma, 2020-2025 yılları arasındaki Web of Science (WOS) verileri kullanılarak zemin iyileştirme araştırmalarının bibliyometrik analizini sunmakta ve VOSviewer yazılımı ile gerçekleştirilmiştir. "soil stabilization," "soil improvement," "ground stabilization" ve "soil reinforcement" anahtar kelimeleriyle yapılan taramada toplam 6.850 makale incelenmiştir. Analiz kapsamında ülkelere göre atıf ve makale sayıları, kurumsal atıf analizleri, ortak yazarlık ağları, anahtar kelime eşleşmeleri ve yazarlar arasındaki bibliyografik bağlantılar değerlendirilmiştir. Sonuçlar, Çin'in 1.580 makale ve 15.685 atıfla lider konumunda olduğunu, onu Hindistan ve ABD'nin takip ettiğini göstermektedir. Singapur, makale başına en yüksek atıf oranına (15,6) sahipken, Hindistan en düşük (8,2) değere sahiptir. Bu durum, bazı ülkelerde yüksek yayın sayısına rağmen uluslararası atıf oranlarının düşük olduğunu göstermektedir. Kurumsal analizde Çin üniversitelerinin alanı domine ettiği, ayrıca İran'daki Islamic Azad Üniversitesi'nin ikinci sırada yer aldığı, ancak İran'ın genel sıralamada üst sıralarda bulunmaması nedeniyle araştırmaların belirli kurumlarda yoğunlaştığı belirlenmiştir. Anahtar kelime analizi, "geosynthetics" teriminin en sık kullanılan anahtar kelime olduğunu ve geosentetik bazlı zemin iyileştirme tekniklerinin giderek daha fazla önem kazandığını göstermektedir. Diğer yaygın anahtar kelimeler arasında "soil stabilization," "ground improvement," "unconfined compressive strength" ve "soil improvement" yer almaktadır. Çalışma, küresel akademik iş birlikleri, yükselen araştırma konuları ve gelecekte keşfedilmesi gereken alanlar hakkında önemli bilgiler sağlayarak, zemin iyileştirme araştırmalarının mevcut durumunu ve gelecek yönelimlerini anlamaya katkıda bulunmaktadır.

Anahtar Kelimeler: Zemin İyileştirme, Bibliyometrik Analiz, VOSviewer, Atıf Analizi, Makale Analizi

1. Introduction

The increasing volume and diversity of scientific research make it challenging to evaluate academic studies in a specific field comprehensively. At this point, bibliometric analysis is a powerful method for analyzing scientific productivity, development trends, influential researchers, collaborative networks, and the most frequently used keywords within a given subject [1]. Bibliometric analysis effectively determines the scope, development process, and fundamental research areas of academic studies within a particular context. However, it also plays a crucial role in systematically examining the academic literature to assess a research field's current state and future directions [2]. Data from reliable databases such as Web of Science (WOS) can be analyzed using software like VOSviewer to visualize and better understand how scientific knowledge is structured and evolves [3, 4].

Bibliometric analysis in civil engineering is crucial for understanding the evolution of new technologies, material usage, and engineering approaches [5, 6]. As the global population continues to grow, the demand for structures such as

residential buildings, roads, and service facilities is increasing, leading to a rise in cement consumption and associated CO₂ emissions [7–9]. Consequently, sustainability has gained significant importance recently [10–12]. In civil engineering, sustainability-related studies focusing on waste materials, recycling, and environmentally friendly practices have steadily increased [13–17]. In parallel, bibliometric analyses in this field have predominantly been conducted on environmental topics such as sustainability and waste management. Soil improvement techniques, which primarily fall within the domain of geotechnical engineering—a fundamental branch of civil engineering—encompass various methods to enhance weak soils' load-bearing capacity while minimizing settlement and stability issues [18]. In geotechnical engineering, improving soil conditions, increasing bearing capacity, controlling settlements, and ensuring the reliability of engineering projects are among the frequently employed techniques [19–23]. The effectiveness and advancement of these methods have been extensively explored in the scientific literature. Intensive research focuses on traditional and modern soil improvement techniques, with numerous academic studies examining their efficiency, environmental impact, and long-term performance. In recent years, there has been a noticeable increase in academic studies focused on developing soil improvement techniques and using novel materials. In this context, systematically reviewing scientific publications and identifying research trends are crucial guides for researchers [1].

Bibliometric analysis is a quantitative approach used to evaluate scientific productivity and the development of academic disciplines [4]. Its theoretical foundations are based on Price's (1963) "cumulative advantage" theory and Lotka's (1926) inverse square law [6]. While Price emphasized the concentration of scientific output among a few researchers, Lotka demonstrated that most authors contribute only one or two publications [1]. This framework serves as a basis for analyzing author productivity and citation distributions.

Another important approach is Zipf's Law, which is commonly applied in keyword frequency analyses and helps identify prominent concepts in the literature [6]. Bibliometric analysis considers publication and citation metrics and sheds light on research collaborations, thematic clusters, and geographical distributions [6]. In this context, tools like VOSviewer play an effective role by visualizing scientific communication networks and revealing the structural dynamics of a research field [4].

This study conducted a bibliometric analysis of publications in soil improvement using the VOSviewer software. A search was performed in the Web of Science (WOS) database for articles published between 2020 and 2025 using the keywords "soil stabilization," "soil improvement," "ground stabilization," and "soil reinforcement." This search was restricted to academic publications classified as "Articles." Additionally, the Web of Science categories were set to "Engineering Civil" and "Engineering Geological," resulting in 7,108 academic publications. After applying a language filter to include only English-language publications, the total number of documents was reduced to 6,850, and the analyses were conducted based on this dataset.

The study includes five different analyses: citation and publication analysis by country, publication analysis by institution, publication and citation analysis by author, analysis of the most frequently used keywords, and bibliometric relationships among authors. Visual representations and graphical illustrations support these analyses to enhance clarity and provide detailed insights into the findings.

This study contributes to the literature by providing a comprehensive and up-to-date bibliometric overview of research in soil improvement between 2020 and 2025. Unlike previous studies focusing on limited time frames or specific subtopics, this analysis integrates multiple dimensions such as publication and citation trends, institutional productivity, co-authorship networks, keyword co-occurrence, and bibliographic coupling of authors. Furthermore, the study reveals the most active countries, institutions, and researchers and identifies emerging trends and underexplored areas, offering valuable insights for future investigations. By doing so, the research supports a better understanding of the current dynamics and collaborative patterns within geotechnical engineering. It contributes to strategic research planning in the domain of sustainable soil stabilization.

2. Data and Methodology

This study was designed to conduct a bibliometric analysis of academic publications on soil improvement. The data collection and analysis processes are presented in detail below using a methodological approach. The Web of Science Core Collection database was used as the primary data source for the bibliometric analysis. On January 11, 2025, a search was conducted for academic studies published between 2020 and 2025, filtering the keywords "soil stabilization," "soil improvement," "ground stabilization," and "soil reinforcement." The searches used titles, abstracts, and keywords, and only publications categorized as "Article" were included.

Additionally, the Web of Science categories were restricted to "Engineering Civil" and "Engineering Geological," and only English-language publications were selected. As a result of this filtering process, a total of 6,850 articles were included in the analysis. For these articles, analyses were conducted on the number of publications and citations by country, the number of publications and citations by institution and author, the interpretation of these findings, the most frequently used keywords, and the bibliometric relationships among authors. The results were visualized, interpreted, and reinforced with various graphical representations. The bibliometric analysis was conducted using VOSviewer software (Version 1.6.20). VOSviewer stands out as software with substantial functional advantages [24]. The "Association

Strength" analysis type of the VOSViewer program was used in all analyses in the study. This analysis type calculates the relative relationship strength by normalizing the frequency of co-occurrence between two elements according to the total frequency of occurrence of these elements [24].

These analyses have been conducted to reveal the academic development dynamics in the field, identify existing research gaps, and highlight potential future research areas [25]. The findings comprehensively evaluate the scientific network structure of academic publications on soil improvement and offer insights into research topics that may gain prominence in the coming years [26]. Furthermore, the results of the bibliometric analysis identify potential collaboration opportunities that could serve as a guide for future research [27]. In this context, the study's findings have implications in the academic domain and industrial applications. Considering the increasing significance of sustainable and environmentally conscious soil improvement practices, the contributions of this study to the field are emphasized [28]. Recommendations for future studies are presented to encourage research into next-generation soil improvement techniques.

While VOSviewer is a widely used and effective tool for bibliometric mapping, it also has certain limitations that should be acknowledged [29]. The clustering algorithm can sometimes oversimplify complex relationships, leading to overlaps or unclear boundaries between clusters [29]. Additionally, the visual representation may be influenced by the selection criteria and threshold settings (e.g., minimum number of occurrences), which may exclude potentially relevant but less frequent terms or authors [29]. Finally, although VOSviewer provides powerful network visualizations, it does not allow for in-depth statistical analysis, which may require complementary tools for further exploration [29].

Within the scope of the study, only articles written in English were included in the analysis, as it was thought that words common to different languages could confound the analysis results since articles written in other languages constitute approximately 1% of the total articles.

3. Result and Discussion

3.1. Citation and Publication Analysis by Country

Analyzing citations and publications by country is highly beneficial in identifying which countries focus more on a particular research topic and how much impact that topic has within each nation [25]. The number of current studies conducted in a given country is a valuable parameter in determining the level of interest and significance attributed to the topic in that region [30]. Additionally, the number of citations received by publications reflects the extent to which research conducted in that country is acknowledged within the international academic community, essentially measuring its degree of globalization [31]. In this regard, the bibliometric analysis of citations and publications by country provides substantial insights for researchers [32].

As a result of the analysis, which was conducted by applying a minimum threshold of 10 publications and 10 citations per country, 54 out of 107 countries contributing to the 6,850 articles were included in the evaluation (Figure 1). According to the findings, China dominates the field with 1,580 publications and 15,685 citations, followed by India (601 publications, 4,924 citations) and the United States (448 publications, 5,847 citations). A graphical representation of the top 10 countries in terms of publication and citation counts is provided in Figure 1.

Singapore's high average citation per publication (15.6) indicates a greater impact of its research output on the global scientific community. This may be attributed to the country's emphasis on interdisciplinary research, strong engagement in international collaborations, and a tendency to publish in high-impact journals. In contrast, despite its high publication count, India's lower citation ratio (8.2) suggests limited international visibility, possibly due to fewer global partnerships or a higher concentration of publications in lower-impact journals.

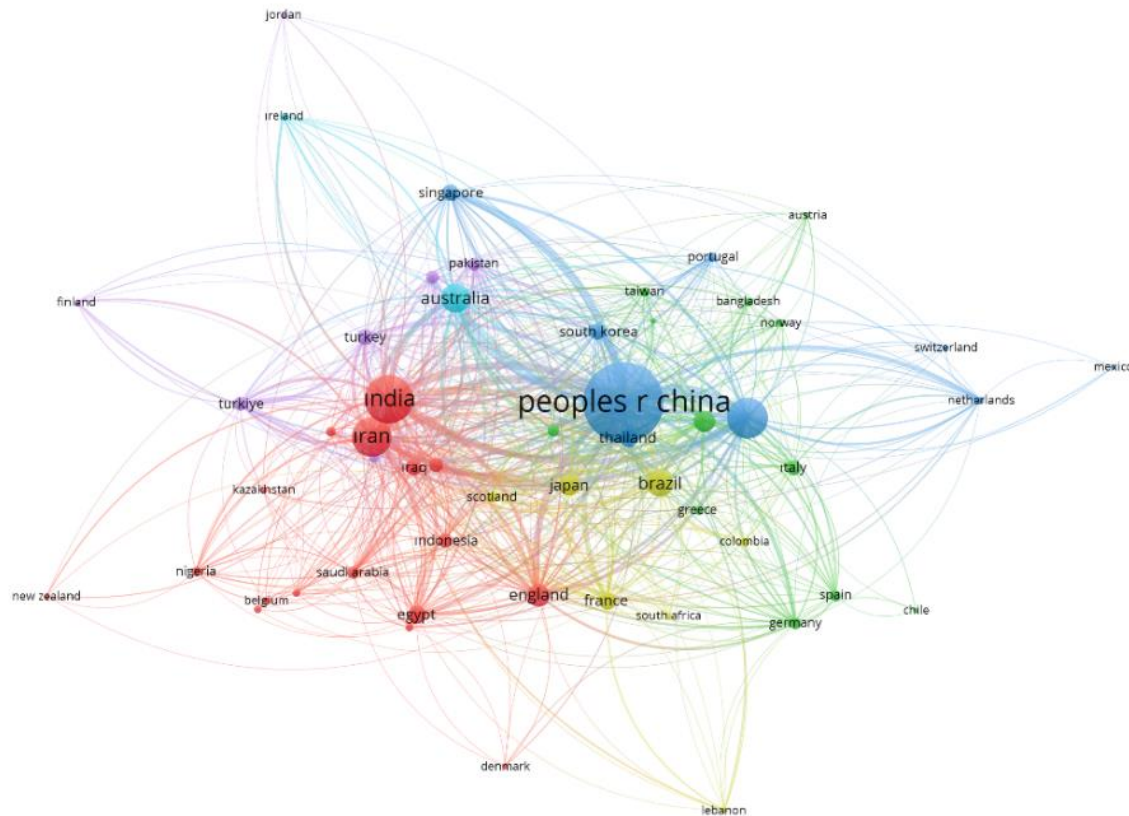


Figure 1. Network structure based on publication and citation counts

Figure 2.a reveals a 1:10 ratio between the number of publications and citations among the top 10 countries. On average, each publication has received approximately 10 citations, with a more consistent distribution observed in countries other than India, the United States, and Australia. Furthermore, when analyzing citation impact, Singapore has the highest citation per publication ratio, averaging 15.6 citations per paper. At the same time, India has the lowest citation rate among the top 10 countries, with an average of 8.2 citations per publication (Figure 2.b).

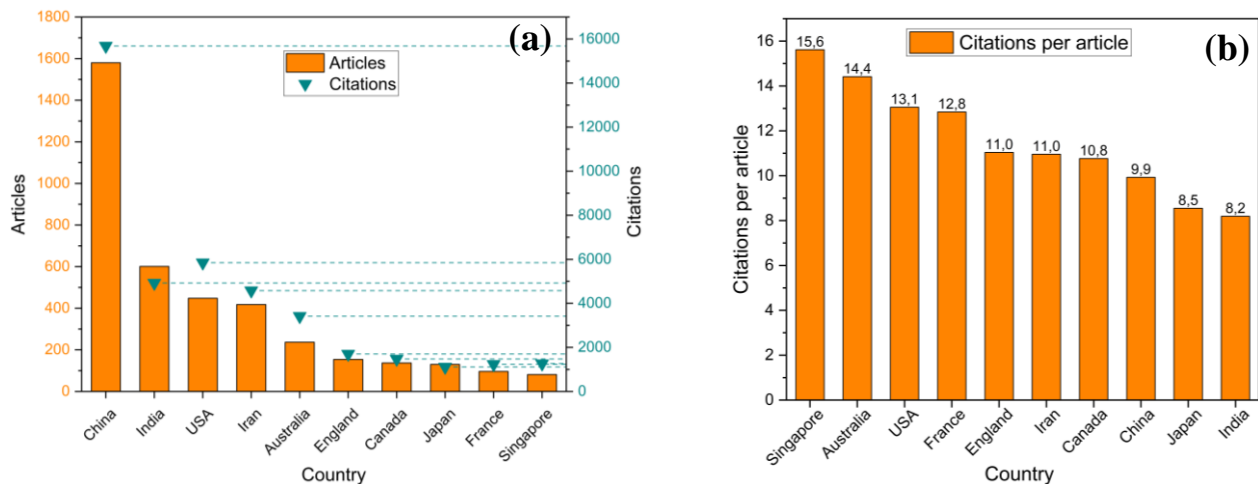


Figure 2. Distribution of the top 10 countries based on the number of publications and citations (a) and average citations per publication (b)

3.2. Citations of Organizations

The citation analysis of institutions primarily indicates the total number of citations received by the publications of a particular university or research institution. Institutions with more citations are naturally considered to have a more significant academic impact [33]. This analytical approach enables the comparison of different institutions' scientific influences [34]. Consequently, the most influential institutions in the field can be identified, academic competition and impact analysis among institutions can be conducted, and potential collaboration opportunities can be determined [33].

When applying a minimum threshold of 10 publications and 10 citations per institution, it was found that 171 out of 3,394 institutions that contributed to the 6,850 analyzed articles met the specified criteria (Figure 3). This indicates that approximately 5% of the institutions met the minimum requirement of 10 publications and 10 citations.

The Chinese Academy of Sciences in China ranks first with 135 publications and 1,076 citations among the institutions with the highest number of publications and citations. Islamic Azad University follows this in Iran with 109 publications and 1,272 citations, and Tongji University in China has 106 publications and 1,363 citations.

In institutional citation analysis, Chinese universities dominate the publication and citation numbers field. The prominence of institutions such as the Chinese Academy of Sciences and Tongji University may be attributed to their substantial research capacity, academic productivity, and international collaboration. On the other hand, despite its high number of publications and citations, the presence of Islamic Azad University contrasts with Iran's relatively lower national ranking, suggesting that a significant share of the country's research output is concentrated in this single institution.

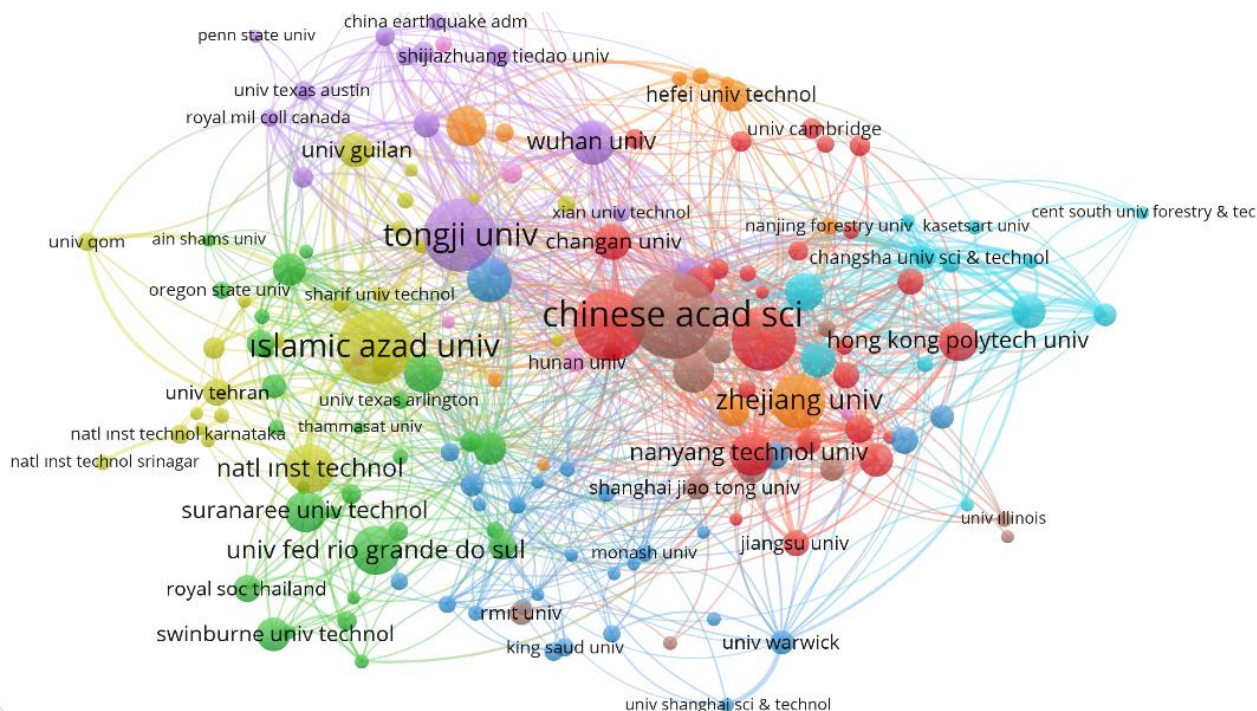


Figure 3. Network structure of institutional connections

3.3. Co-authorship of Authors

This type of analysis identifies how frequently two or more authors collaborate on publications [30]. It provides insights into which researchers have the highest levels of collaboration, facilitating the identification of academic networks, research groups, and key collaborations within a given field [31]. This method is widely used to determine the most influential and highly connected authors in a research domain.

The co-authorship analysis was conducted to identify authors with the highest collaboration levels and create a visually compelling network map. A minimum threshold of 10 publications and 10 citations per author was applied to ensure clarity and enhance the visual representation of the co-authorship network. As a result, among 11,990 authors contributing to the 6,850 analyzed articles, only 69 authors met the specified criteria. The findings indicate the formation of 23 distinct research groups (Figure 4). Additionally, the results highlight that Suksun Horpibulsuk stands out as the most connected author in the field, with 43 publications and 568 citations. Similarly, Arul Arulrajah, with 32 publications and 508 citations, is identified as the second most well-connected researcher. However, despite having the highest number of publications (44) and citations (698), Nilo Cesar Consoli ranks lower in total link strength than the other two authors. This suggests that although Consoli's work has a significant academic impact, his direct co-authorship connections are fewer than those of Horpibulsuk and Arulrajah.

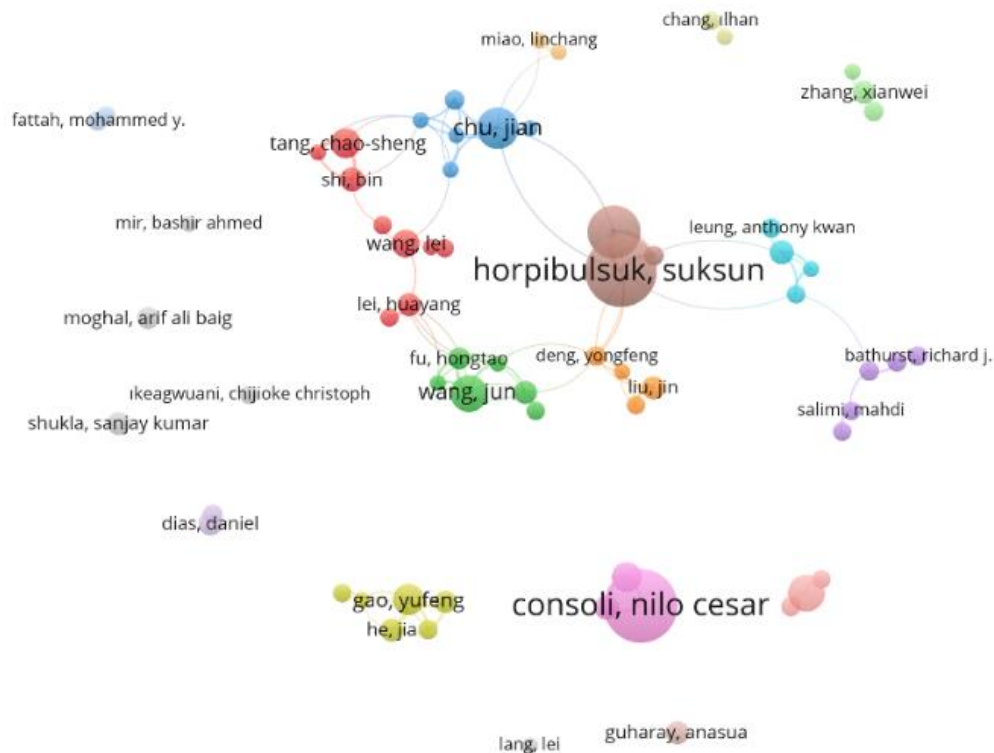


Figure 4. Co-authorship network illustrating collaborations among authors

The co-authorship analysis reveals that some authors with many publications are engaged in relatively limited collaborative networks. This may indicate a tendency to work within closed or narrowly defined research groups with limited international cooperation. Conversely, some authors with fewer publications demonstrate broader collaboration through strong connections with multiple researchers, suggesting that the strength of the co-authorship network can influence citation impact, regardless of publication count.

3.4. Co-occurrence of All Keywords

This analysis examines the most frequently used keywords and their relationships in a specific research field [25]. Keyword analysis reveals which topics are prominent in the literature, identifies research trends, and illustrates how keywords are interconnected. Doing so provides researchers with insights into popular topics, visualizes keyword associations, and serves as a guide for identifying new research directions or refining the focus of an ongoing study [37]. Additionally, keyword analysis is instrumental in tracking the evolution and development of a research field over time [25].

In this section, keywords that appeared in at least 10 different publications were filtered for analysis. Out of a total of 10,117 keywords, 257 were found to have appeared in 10 or more articles (Figure 5). Examining the most frequently used keywords in the selected publications reveals that "geosynthetics" was the most commonly used keyword, appearing in 272 articles. This was followed by "soil stabilization" (267 occurrences), "ground improvement" (241 occurrences), "unconfined compressive strength" (215 occurrences), and "soil improvement" (162 occurrences). Figure 6 illustrates the top 10 most frequently used keywords, along with the number of different publications in which they appear.

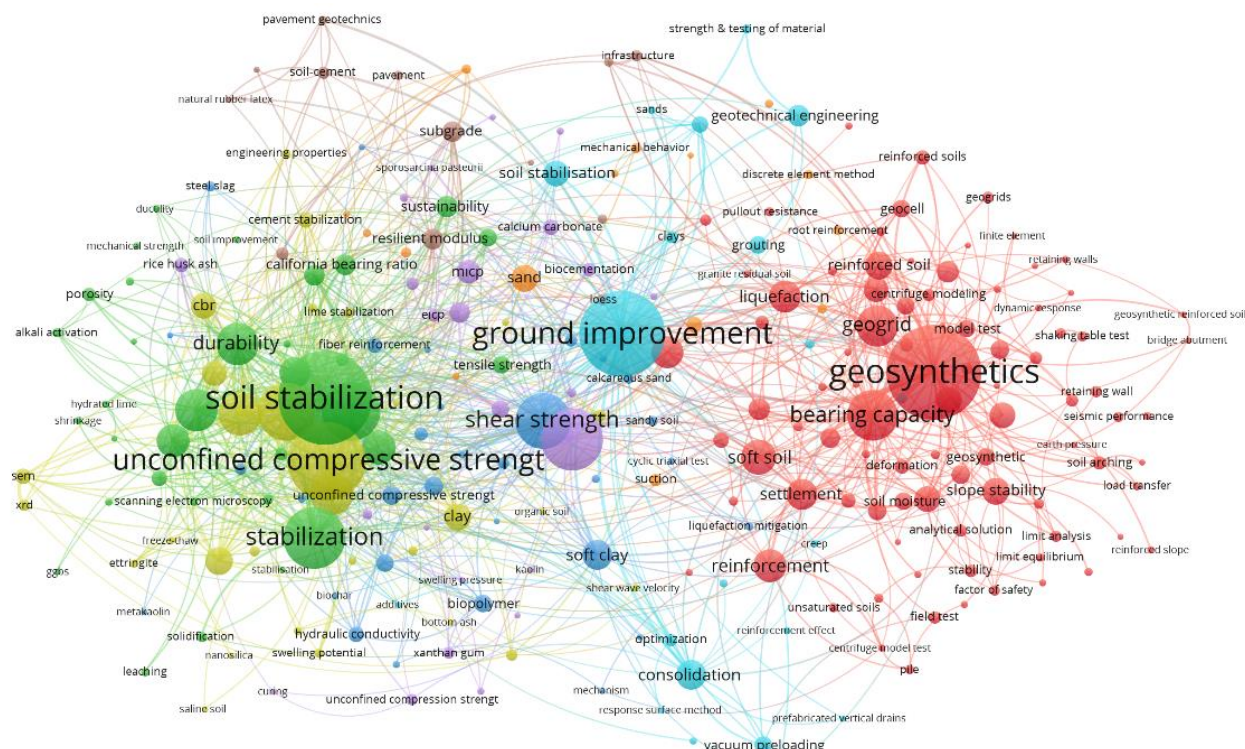


Figure 5. Network structure based on keyword usage frequency

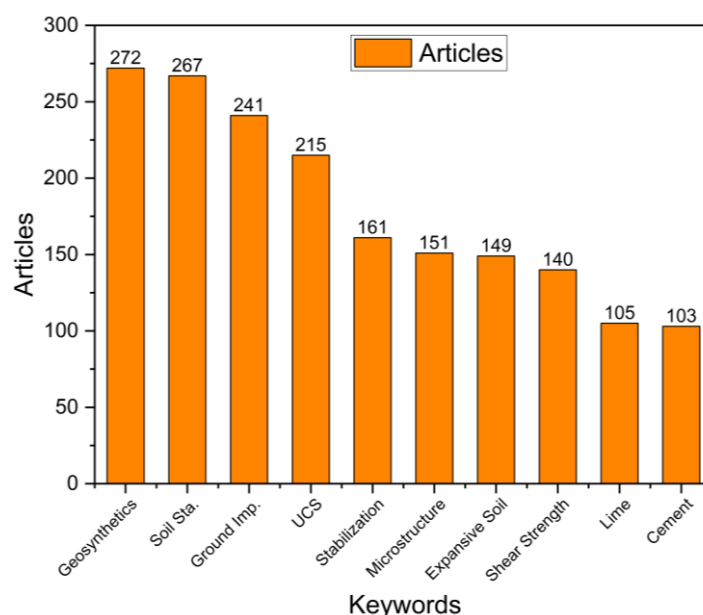


Figure 6. Number of different publications where keywords from the top 10 countries appear

Within the study's scope, only English articles were included in the analysis, as it was thought that words common to different languages could confound the analysis results. The keyword analyses presented in Figures 5 and 6 reveal bibliometric density and highlight the dominant technical methods and materials used in soil improvement studies. The frequent occurrence of terms such as “geosynthetics,” “clay,” “lime,” “cement,” and “fly ash” suggests that much of the research has been conducted on fine-grained soils (e.g., clay), with a focus on traditional binders and industrial by-products as stabilizing agents. This provides valuable insight into the geotechnical relevance of soil types and the improvement strategies applied to them. The clustering of keywords also emphasizes themes such as mechanical strength, environmental sustainability, and laboratory testing methods, further illustrating the field's interdisciplinary nature. Articles written in other languages constitute approximately 1% of the total articles.

countries in terms of overall publication impact. This suggests that research output in Iran is concentrated within a few institutions rather than evenly distributed across multiple research centers.

- c. Examining co-authorship among authors, it is evident that some researchers with higher citation and publication counts rank lower in terms of collaboration than those with fewer citations and publications. This indicates that specific authors work within limited research groups or are not frequently involved in multinational collaborative studies.
- d. The keyword analysis of articles revealed that "geosynthetics" was the most frequently used keyword, highlighting the growing prominence of geosynthetic-based soil improvement methods in recent years. This finding provides valuable insights for researchers exploring emerging research topics or staying updated with current trends. The following most frequently used keywords were "soil stabilization," "ground improvement," "unconfined compressive strength (UCS)," and "soil improvement." These are commonly associated with soil improvement research, so their high frequency is unsurprising. Additionally, "lime" and "cement" emerged as notable keywords, suggesting that cement- and lime-based soil stabilization techniques remain relevant and widely studied.
- e. The bibliometric relationship analysis among authors confirms that authors with many publications are often among the most frequently cited researchers by others. This serves as an indicator of their influence and recognition within the international scientific community.
- f. The international name of the Republic of Türkiye was officially changed from "Turkey" to "Türkiye" by the United Nations (UN) in 2022. To avoid confusion in the analyses conducted for the 2020-2025 period, all publications originating from Turkey or Türkiye between 2020-2025 were collected under the title of Türkiye.
- g. This study presents a bibliometric analysis of soil improvement techniques, which remains a relatively niche research area. However, civil engineering and its various subfields require comprehensive bibliometric analyses to map their development trends. Future studies can extend the time frame from five to ten or twenty years to examine how research trends have evolved. Additionally, cross-disciplinary bibliometric analyses can be conducted to explore the relationship between civil engineering and other engineering disciplines. A broader and more general bibliometric study on civil engineering may also benefit. Furthermore, future studies could incorporate data from other databases, such as Scopus, and apply different methodological constraints to expand the scope of analysis.
- h. In future studies, the scope year can be further expanded; thus, the change in soil improvement from past to present can be revealed more clearly.

Conflict of Interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethics Committee Approval

Ethics committee approval is not required.

Author Contribution

The author have read and agreed to the published version of manuscript.

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