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Global Research Trends in Engineered Soil Development through Stabilisation: Scientific Production and Thematic Breakthrough Analysis

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Abstract: Soil, a naturally occurring resource, is increasingly used as a construction material. Stabilisation strengthens soil, which is weak as an engineering material. Stabilising soil changes its physical qualities, enhancing its strength. Soil stabilisation increases the shear strength and load-bearing capacity. Soil stabilisation refers to any endeavour to change natural soil for engineering purposes using physical, chemical, mechanical, or biological methods, or a mix of these. Strengthening road pavements includes improving the load-bearing capacity, tensile strength, and performance of unstable subsoils, sands, and waste materials. Due to market demands and scientific advances, the number of soil-stabilising additives has increased. These innovative stabilisers include reinforcing fibres, calcium chloride, sodium chloride, and cross-linking water-based styrene acrylic polymers, which are geopolymers that boost the load-bearing capacity and tensile strength of soil. Many materials are being explored for soil stabilisation. In this article, the authors investigated the direction of soil stabilisation research. Scientometric analysis identifies stabilisation challenges and research trends in the field. This study analysed research patterns by countries, authors, institutions, keywords, and journals from 1959 to 2023; in 2021, 150 articles were published, which was the highest number in a year. Citations peaked at 3084 in 2022. With 253 publications and 3084 citations, India was the most productive country. Iran and France published the fewest, 34 and 33, respectively. The Islamic Azad University and the National Institute of Technology had the fewest published articles with 17 articles. This work can help track soil stabilisation research and will serve as an information document for future research.

Keywords: soil stabilisation; expansive soil; fibre reinforced soil; scientometrics; trend analysis; research trend mapping; bibliometrics

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1. Introduction

Expansive soils that exhibit swell–shrink characteristics when exposed to water are treated as highly problematic soils when considered for civil engineering purposes [1]. They are frequently found in many parts of the world and can cover large portions of countries. The widespread use of natural resources to fuel the building industry's rapid expansion is a major cause of concern among eco-activists. When constructing roads, bridges, and other infrastructures on expansive soil, which expands and contracts depending on the weather, civil engineers face many challenges. Over 20% of India is made up of black cotton soils [2–5]. Variations in the moisture content cause these soils to exhibit considerable differences in swelling, compressibility, and shear strength, ultimately resulting in structural failure. When soil fails, the structure resting on the soil also becomes vulnerable,

and hence, strengthening the soil to increase its durability is mandatory. Various methods have been employed to enhance the soil's strength; one such method is stabilisation, which is performed by utilising chemical and mineral admixtures either together or individually. Soil stabilisation is a method adopted to improve the soil's mechanical strength, permeability, compressibility, durability, and plasticity, among other desirable technical features [6]. Physical and mechanical methods exist for enhancing the soil quality, but the term "stabilisation" is used to refer to the incorporation of chemical admixtures into soil to improve its quality. Engineering structures including backfill for bridge abutments and retaining walls, as well as sub-base constructions and development of basements, foundations, and embankments, are examples of structures that benefit from stabilised soil. Soil stabilisation is a vital element of most building projects, from the commercial construction to environmental rehabilitation [7]. Soil stabilisation is the process of transforming unconsolidated unstable soil into a more rigid stable medium that can support constructed structures, change permeability, alter subsurface movement, or immobilise pollution by mineral precipitation. Multiple materials and techniques are studied and employed in soil stabilisation to make it more suitable for construction purposes [3,8,9].

Various chemical additions, including lime, cement, blast furnace slag, cement slag, coffee seed ash, agricultural waste ash, gypsum, fly ash, nano silica, silicate compounds, geopolymers, sulfonated oils, ammonium chloride, enzymes, potassium compounds, polymers, ammonium and potassium lignosulfonates, barium chloride, barium hydroxide, and bio-enzymes have been utilised to stabilise unstable soils for earthwork applications [10–15]. Soil stabilisation with chemical addition can be employed to strengthen soils with poor engineering qualities, and it can also be used for engineering purposes. Most of these conventional soil stabilisers are only applicable to specific soil types. In some instances, traditionally stabilised soils exhibit a high degree of brittleness, which is frequently unsuitable for projects such as airport runways and railroad embankments. Extensive research has been carried out recently on the influence of non-traditional additives on the geotechnical characteristics of soils. It is generally known that the size, shape, and arrangement of soil particles, as well as the plasticity index (PI), have an impact on how natural soils are treated with additives. Atterberg limits, proctor compaction, unconfined compressive strength (UCS), the impact of cyclic wetting/drying on strength parameters, stress–strain behaviour, and secant modulus of elasticity are just a few of the essential properties of high-plasticity clay that are assessed [9]. Clay that has been subjected to lignosulphonate-treatment (LS-treatment) and clay that has not been subjected to LS-treatment are analysed using scanning electron microscopy (SEM) to determine the strength increase caused by the treatment.

The effective stress parameter is more difficult to calculate for swelling soils due to their multi-scale nature (macroscopic, mesoscopic, and microscopic). Here, the saturating power of a given interaction scale is linked to the parameter. The hydro-mechanical behaviour of samples with varying degrees of compaction (loose, moderate, and dense) was investigated using an effective stress technique. Using this method, we are able to specify the plane-parallel yield surfaces for the compacted samples. Numerous research works have evaluated the feasibility of stabilising black cotton soil (BCS) by mixing it with sawdust, a common and cheap substance. The liquid limit, differential free swell, and PI of BCS stabilised with 4% lime were the lowest possible values, while California bearing ratio (CBR) and the specific gravity were the highest possible values [14]. The utilisation of agricultural by-products like rice husk ash (RHA) in soil stabilisation is one of the most cost-effective and eco-friendly methods available. UCS and CBR values reported from various studies show that specimens cured for 28 days with 6% RHA and 8% cement have the highest values, at 25.44 and 18.2 times higher, respectively, compared to values for untreated soil. A SEM study of the aforementioned stabilised soil revealed a matrix of well-structured soil with extremely small holes owing to the pozzolanic reactions of cement and RHA. Soil stabilisation efforts have similarly explored the use of a wide variety of agricultural by-products such as pozzolanic material [16]. Extensive research is undertaken,

and some of the investigations focusing on stabilising soils and their studied parameters are provided in Table 1.

Table 1. Research results on soil stabilisation.

Reference	Journal	Used Stabiliser	Performed Test	Type of Soil	Major Outcome
Zafar et al. [3]	Materials Today: Proceedings	Natural and synthetic fibres	CBR, UCS, aspect ratio, modulus of elasticity, swelling, compressibility	Expansive soil	Improvement of expansive soil characters
Pahlevi Munirwan et al. [9]	Physics and Chemistry of Earth, Parts A/B/C	Coffee husk ash	Chemical, physical, microstructural properties, water/CHA ratio, optimal burning	Subgrade soil	Enhancement of strength
Wang et al. [14]	Soils and Foundations	GFC soil stabiliser	Optimal ratio, UCS, SEM, XRD	Soft marine clay	Increase of strength
Al-Atroush and Sebaey [15]	Transportation Geotechnics	Hydrophobic polyurethane foam	Swell-shrink nature, chemical and physical, microstructural	Expansive soil	Reduction of swell–shrink nature
Luo et al. [17]	Case Studies in Construction Materials	Slag, fly ash based geopolymer	UCS, bearing capacity, mass, immersion	Soft soil	Increase of bearing capacity
Sundary et al. [18]	Physics and Chemistry of Earth, Parts A/B/C	Lime	Morphological and physical properties, strength, compressibility	Sediment soil	Change in morphology
Dai et al. [19]	Soil Dynamics and Earthquake Engineering	Super absorbent polymer	Triaxial test, consolidation, damping ratio, elastic modulus	Cement-stabilised soil	Obtaining high elastic modulus
Espinosa et al. [20]	Materials Today: Proceedings	Ladle furnace slag	PI, UCS, elasticity, CBR, shear strength	Clayey foundation soil	Increase of CBR
Hamid et al. [21]	Case Studies in Construction Materials	Geopolymer	UCS, MDD, OMC, compressive strength	Saline sabkha soil	Enhancement of strength
Kommidi et al. [22]	Transportation Geotechnics	Chemical stabilisers (C-A-H, C-S-H)	UCS, freeze–thaw, dynamic mechanical analysis, shear stress, strain energy	Subgrade soil	More freeze–thaw resistance
Nan et al. [23]	Cold Regions Science and Technology	Quick lime	UCS, FTC, freeze–thaw	Saline soil	More freeze–thaw resistance
Pandey et al. [24]	Transportation Geotechnics	Magnesium phosphate cement, jute fibre	UCS, elastic modulus, swelling	Kaolinitic soil	Good elastic modulus with reduced swell
Ren et al. [25]	Science of The Total Environment	Phosphogypsum slag-based cementitious materials	XRD, TGA, FTIR, XPS, SEM/EDS	Lead-contaminated soil	Leaching effect was analysed and strength variation was studied

Table 1. *Cont.*

Reference	Journal	Used Stabiliser	Performed Test	Type of Soil	Major Outcome
Yu et al. [26]	Engineering Geology	Carbonated steel slag	UCS, D-W Cycles, Rm	Soft soils	High D-W resistance
Owino et al. [27]	Construction and Building Materials	Basalt fibre filaments	Triaxial test, OMC, MDD, SEM, XRD	Chemically stabilised weak soils	Improvement of shear strength

Based on the information presented in the above table, it is clear that many stabilisers have been studied for their effectiveness. Lime and cement are the most common materials used for soil stabilisation; while there are numerous other options, these two are both widely studied and have also been employed in the field for longer. These stabilising agents are useful, but they come with their own set of problems, such as negative effects on the environment (in the form of CO_2 emissions, increased energy usage, and higher costs). Also, while adding lime or cement can boost a soil's technical properties, it may have unintended consequences for other qualities [6]. For instance, when sulphate is present, these additions may produce undesirable growth. Some of these, such as GFC soil stabiliser, ladle furnace slag, fly ash-based geopolymers, chemical stabilisers (C-A-H, C-S-H), natural and synthetic fibres, magnesium phosphate cement, jute fibre, basalt fibre, filaments, rice husks and polypropylene fibre, quick lime, lime, super absorbent polymers, geopolymers, coffee husk ash, carbonated steel, slag, phosphogypsum slag-based cementitious materials, and many more, are also being studied [6,11]. All these stabilisers were added in different dosages and most of the research works involved obtaining the optimum dosage with reference to the soil selected. Some of the studies utilised both stabiliser and a fibre to increase the strength [3]. Behnood [6] conveyed that any cementitious materials, such as Portland cement or lime, can be employed to stabilise soil, but the resulting product takes on the characteristics of both the soil and the stabilisation reagent. The characteristics of the soil, such as particle size distribution (PSD) (or gradation), chemical composition and minerology, plasticity characteristics, organic matter content, salt (mainly sulphate) content, cation-exchange capacity, pH, specific surface area, etc., influence the efficiency of the stabilisation process in addition to the type and quantity of the used cementitious materials. Gained qualities of stabilised soils may also be affected by the construction method and quality (e.g., compaction effort), curing state, and duration [6,13,17,18,28,29].

To understand the behaviour of soil and the impact of stabilising agents, multiple parameters of soil are studied by various researchers. Some of these are pH, PI, optimum moisture content (OMC), maximum dry density (γ_{dmax}), UCS, CBR, linear shrinkage, modulus of elasticity, hydraulic conductivity, cohesion, freeze–thaw resistance, swelling, liquid limit, plastic limit, shear strength, permeability, splitting tensile strength, stress–strain variation, PSD, and carbonate content. Many studies targeted the above-mentioned parameters and analysed the effect of stabilisers to modify these parameters to suit the needs and demands of a given structure [28,30–41].

Thus, it is very evident that soil stabilisation and research related to it should be understood and disseminated properly, which is the main aim of this research article. There are many review articles developed by authors from a number of countries and provided information related to various methods implemented to stabilise soil and their effectiveness, but there are no published articles analysing research trends [6,10,15,42–48]. Hence, the authors have made an attempt to analyse the research progress in the soil stabilisation domain by carrying out a scientometric study using the citation database, Scopus. The scientometric analysis is mostly conducted to unearth research progress by understanding the citations and tracking them. In this work, we have analysed the journals involved in research, authors who have contributed, articles metrics, and keywords involved in the research. This type of study will throw light on what kind of work is being undertaken, who is undertaking it, where it is being undertaken, what keywords are involved, and

how it is performed. Through this understanding, new researchers can improve their understanding of the field.

2. Scientometrics and Research Significance

The field of the study known as "scientometrics" examines the numerical components of the scientific method as a means of dissemination. The study of scholarly citations is central to its goals but is by no means exclusive. As time has progressed, it has become increasingly important to gauge the efficacy of scientific investigations. This overview considers the origins of scientometrics, citation data sources, citation metrics, the "laws" of scientometrics, normalisation, journals' impact factors and other journals' metrics, visualising, evaluating, mapping science, policy, and future developments [1]. The fields of scientometrics and bibliometrics evaluate how scientific knowledge is disseminated and used, as well as track and assess research outputs like journal articles, books, and conference papers. Many bibliometric studies centres on authorship or measure the contribution of journals and research organisations [49]. We have adopted a scientometric approach towards analysing the trends happening in the research related to soil stabilisation for swelling soil. The aim of this work is to provide information related to the attributes of various research contributions, including contributors, countries, affiliations, and keywords involved, and not to serve as a review of the works carried out and their obtained results.

3. Methodology

3.1. Method

Scientometric analysis was used to rank the articles written about the development of engineered soil through soil stabilisation. Scientometrics is a quantitative and statistical method for analysing publication patterns in scholarly works like research articles, conference papers, and other scholarly documents [49–51]. The Scopus database was combed through extensively on www.scopus.com in January 2023. To minimise the possibility of bias introduced by daily updates to the databases, the search was conducted on a single day. For this study, we looked back at articles indexed by Scopus from 1959 to date. The amount of data in Scopus has made it the database of choice for many scientometric and bibliometric studies [51]. Scopus is widely recognised as the most comprehensive and trustworthy database of scholarly articles. Many scientists have started using it as a bibliometric data source. The goal of the authors of this investigation was to provide a scientific panorama of the many people, places, and groups that have worked together to advance our understanding of how engineered soil can be developed through soil stabilisation. The acquired data's intellectual (co-citation network) and social (collaboration network) structures were also examined (co-occurrences of authors/keywords, thematic evolution). Figure 1 illustrates the methodology adopted in this research to perform scientometric search.

3.2. Search Query

Databases like Scopus and Web of Science provide information through a search query and the information can be retrieved in any file format required. To retrieve the scientometric data on the development of engineered soil through soil stabilisation, the following search query was run in the main search interface of the Scopus database in the search field type:

(TITLE-ABS-KEY (soil AND stabilisation) AND TITLE-ABS-KEY (swelling AND soil))

The search was executed in the Scopus database during January 2023, and the data were obtained as .csv files that are interoperable and accepted by various bibliometric software, including Biblioshiny (version 4.1.3), which was utilised in this study [51,52]. The obtained data were curated using Excel, and all outliers, such as dummy information, were removed before processing.

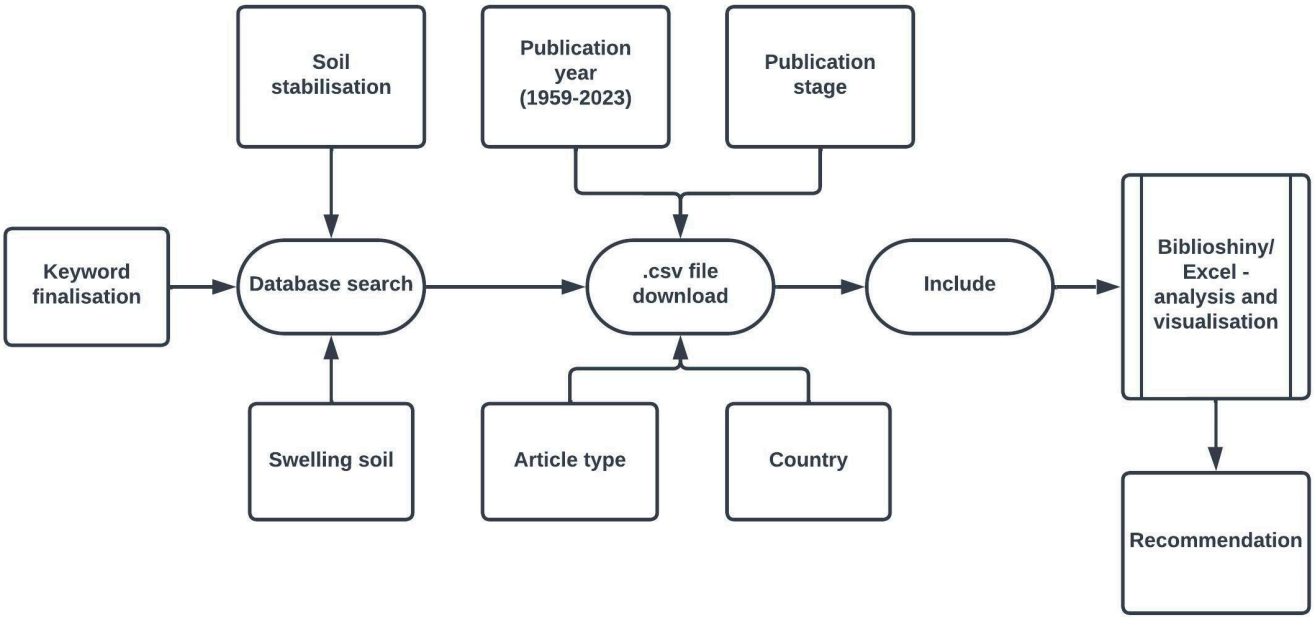

Figure 1. Methodology of this research.

3.3. Inclusion/Exclusion Criteria

The initial search retrieved 951 documents. Limiting the publication period from 1959 to 2023 resulted in 918 documents. Applying filters such as limiting the publication stage to 'final', top ten countries publishing articles in the field of the development of engineered soil through soil stabilisation, and setting document type to articles, conference papers, book chapters, reviews, and books, retrieved 918 documents. The language considered for the documents was only English. The final 918 records consisted of articles (n = 438), conference papers (n = 139), book chapters (n = 15), and the remaining records, which were other publications that indexed in the period of study. This article presents a hybrid approach to systematically assess research on the development of engineered soil through soil stabilisation by integrating scientometric and complex network analyses. It was checked that the selection of items was consistent, and the data were correct. It should be noted that this search is time dependent, and the database is updated regularly; hence, the numbers mentioned above may vary for more recent searches. Details of the above-mentioned data are presented in Figure 2.

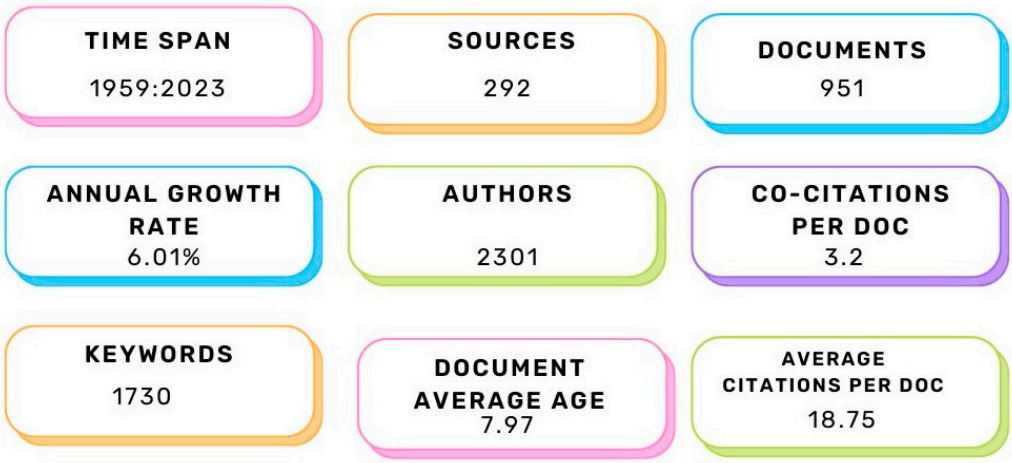

Figure 2. Summary of main results of bibliometric analysis.

3.4. Data Analysis

In this article, various bibliometric tools, including Biblioshiny, Excel, and VoSViewer were employed to perform the basic functions and achieve meaningful interpretable results from the data obtained from Scopus, including publication information and citation trends. The data were utilised to produce graphs by using OriginPro 2022b (64-bit) and Biblioshiny (version 4.1.3). The information achieved through this action helped the authors conduct data visualisation to interpret the progress of research related to soil stabilisation by exploring individual publications. The obtained data from Scopus were in .csv format, which is widely used and accepted, and interoperable among various bibliometric software. Through the usage of this tool, various factors, including citation trends, publication trends, coupling, co-citation, and co-authorship networking, were obtained [49]. Considering the length requirement for this article, only the most required bibliometric parameters are presented herein.

3.4.1. Analysis of Overall Growth Trend

Figure 2 summarises the main results of the bibliometric analysis to describe the collection size in terms of for example, total documents, number of authors, number of sources, number of keywords, time span, references, and average number of citations. Furthermore, many different co-authorship indices are displayed. This analysis demonstrated the total input data in Biblioshiny, and a total of 918 articles were published on soil stabilisation. Authors of single-authored documents are highly accredited in the academic world, and this particular domain has a considerable number of single-authored documents (67), which indicated the interest among authors. Co-authors per document were found to be 3.18, which was less than average. The average number of citations per document was 18.48, signifying a considerable number of citations which might be attributed to the reception among the research community. Keywords were the defining parameters to retrieve a research article online, and they also depicted the main content/theme of the work. In this research, we found that 1664 different author-defined keywords were involved in describing research related to soil stabilisation. The entire research field was spread over these keywords, which in a number of publications were exclusively submitted by authors; the most widely used keywords are analysed in this article.

Figure 3 shows the publications and citations by year, with reference to the development of engineered soil through soil stabilisation research from 1959 to 2023. The number of publications and citations has significantly increased over the years. In 2021, a greater number of articles was published, 150, which was the most productive year, while a greater number of citations was obtained in 2022 (3084). The number of publications in a particular time period defines the interest among authors, funding agencies, and institutions involved in research, and if this value is more than average, it illustrates considerable interest.

3.4.2. Top Ten Publishing Countries

Figure 4 presents the highly productive countries involved in soil stabilisation research, in which India is leading with a publication record of 253 in total, followed by the USA (247), China (67), Turkey (59), and Australia (48). Should someone wish to enhance the amount of collaborative research carried out, one good indicator is to note how many researchers are working in a specific field and the number of publications coming from a given country. Citations are used to understand how familiar a particular article is among peers in the field, and in terms of citations, India had an outstanding record with 3084 citations in total, followed by the USA with 1773 citations (information obtained from the data). However, care should be taken to analyse and understand the nuances of citations since trends are influenced by many parameters, and citation distribution remains highly skewed [53,54]. Also, the highest citation (21.96) was recorded for Iran, despite the country producing only 34 publications.

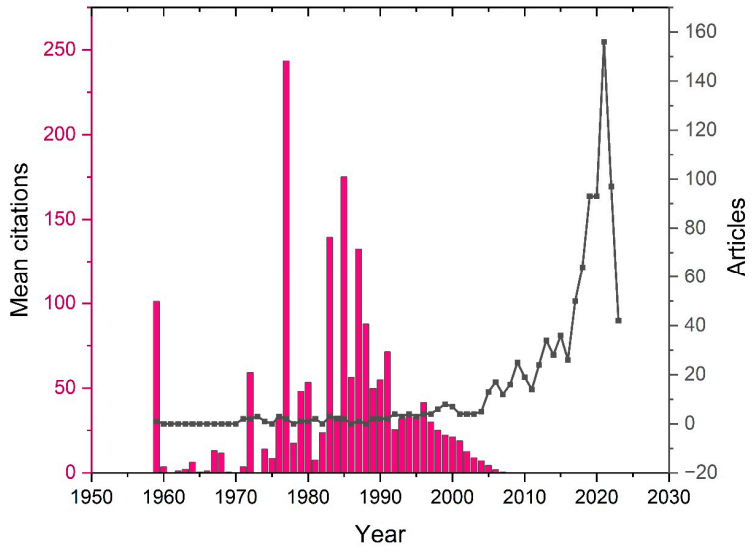

Figure 3. Publication and citation trends on keywords of "soil stabilisation" and "swelling soil" (1959–2023).

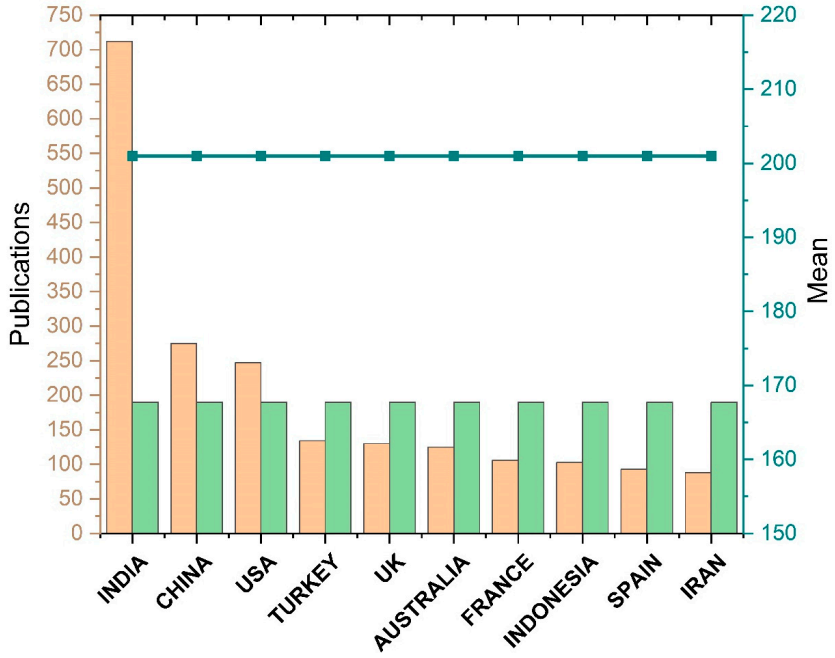

Figure 4. Highest-publishing countries with their respective citations.

3.4.3. Top Ten Research-Producing Institutions

Figure 5 displays the research organisations with the highest research output in the context of this study. All the top ten organisations had more than 10 publications, and the top two organisations had 27 and 26 publications, respectively. The SRM Institute of Science and Technology, with 27 publications, emerged as the top publisher, followed by RMIT University, Jordan University of Science and Technology, and the Indian Institute of Technology Madras, producing 26, 23, and 20 articles, respectively. These institutions are working extensively on stabilisation research and producing a greater number of articles with these keywords.

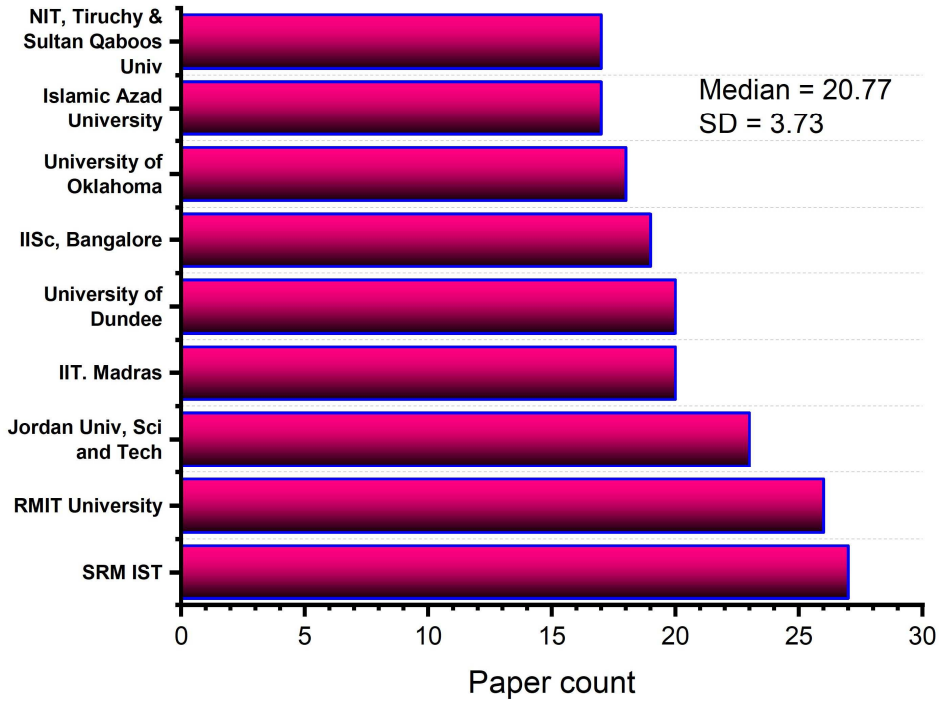

Figure 5. Top ten most highly productive organisations.

3.4.4. Most Prolific Authors

Figure 6 depicts this study's results on the top ten most prolific authors who contributed to the topics of "soil stabilisation" and "swelling soil" during the period of 1959–2023. These authors have contributed research publications related to these keywords very consistently. Puppala AJ from the USA topped the list with 16 documents and 3084 citations. In addition, Puppala AJ has the greatest h-index, which indicates that he is still, by far, the most influential author in soil stabilisation and swelling soil. The annual average number of citations for a work by Puppala AJ is 5.7. Horpibulsuk S of Thailand is the field's second-most prolific academic. Horpibulsuk S has authored 10 works and has an h-index of 8. In 2009, Horpibulsuk S published twice in the field of soil stabilisation and swelling soil; between 2009 and 2020, he published 10 articles; he did not publish work in 2022. Our data also demonstrate that Phanikumar BR and ArulRajah A each has an h-index of 8, implying that they have made remarkable contributions to the advancement of engineered soil through soil stabilisation. Figure 7 provides the work of several other notable academics in this area. The productivity of the top 10 authors over the years is illustrated in the following manner: The line represents the author's publication history; the size of each bubble gives the number of documents produced by the author that year; the depth of the bubble's colour displays the total number of citations that year; the first bubble on the line shows the year the author first published in the field; the larger the bubble, the greater the number of articles published by the author that year.

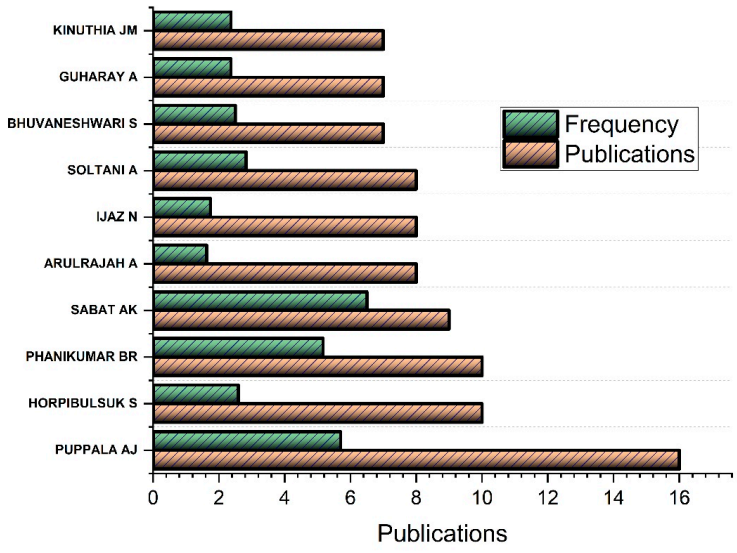

Figure 6. Research output of top ten authors over time.

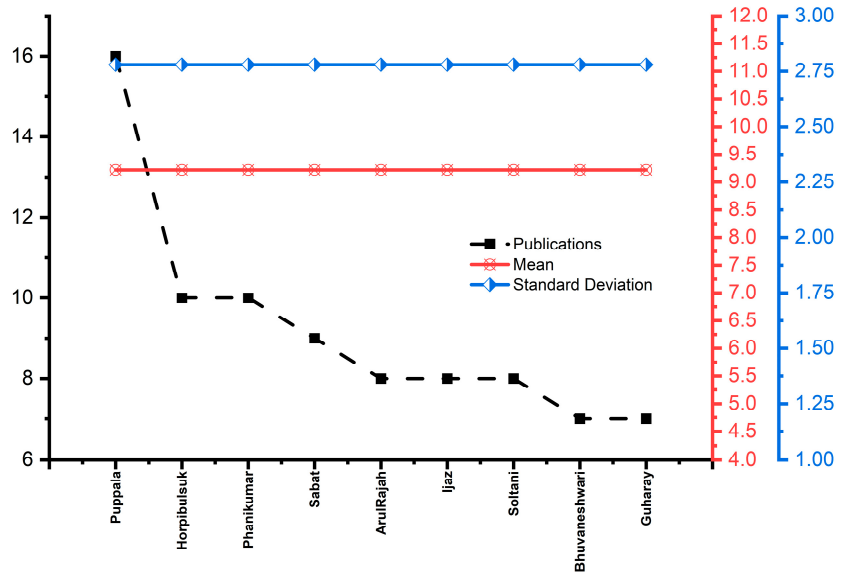

Figure 7. Author impact by h-index.

3.4.5. Three-Factor Analysis

(a) Keywords, authors, and countries

Figure 8 illustrates a more visual representation of the prominent researchers in the field of soil stabilisation and swelling soil in relation to their home countries and their research interests. This figure demonstrates a three-dimensional scatterplot of article contributions to the field of soil stabilisation and swelling soil, broken down by country, author, and topic. In the figure, column 1 presents countries with significant activities, column 2 lists the names of researchers who have made noticeable contributions from those countries, and column 3 represents the most frequently used terms across the articles. In this analysis, 'themes' were formed by the frequency with which certain terms appeared. It is important to note how tall the boxes are and how thick the lines are that connect them. In terms of author affiliations per country, Australia led the group with 612 authors having some sort of link to the country, followed by India (104), the USA (80), and China (61). By inspecting the width of the connection between countries and authors, we can see that Evans R and Al-Taie A continued to be the most significant contributors from Australia.

Puppala AJ was the most prolific Indian author contributing a greater number of articles than any other researcher in the country.

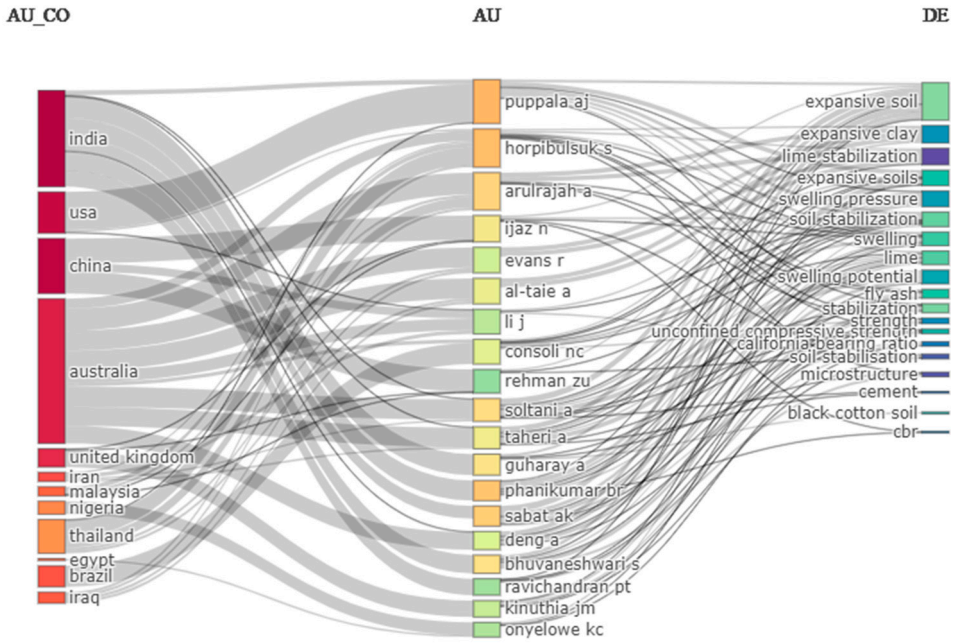

Figure 8. Three-field plot depicting various keywords connected to authors and countries involved in soil stabilisation and swelling soil.

The most important aspect of a three-field plot is the boxes' height and the thickness of the lines connecting the fields; the former displays the level of significance, while the latter indicates the degree of correlation in terms of output.

(b) Thematic evolution of keywords

Figure 9 shows the evolution of keywords in two different stages (1959–2000 and 2001–2023). It can be noticed that most of the research in the second stage related to swelling and stabilisation [55]. This has been supported by the height of the boxes and the thickness of the connecting lines during the period of 2001–2023, which demonstrated the increased research focus on these two terms.

3.4.6. Thematic Map

The study also included a thematic map examination of soil consolidation and expansion. One reason to create a thematic map is to learn more about the state of the field and its prospects for the future; it has also been carried out by other researchers in bibliometric studies [49,56]. Researchers and stakeholders can benefit from this analysis by learning more about the possibilities for future research growth of specific themes within a subject. Clusters of keywords and their associations are used in thematic analysis to derive overarching concepts. Properties, such as density and centrality, define these motifs. The axis illustrating density is vertical, whereas the axis displaying centrality is horizontal. In the thematic map, density quantifies how well-connected each issue is to others, while centrality assesses the strength of ties between them. These two characteristics determine the relative significance and depth of certain issues. The more connections a node in a thematic network has to other nodes, the more central and important that node is, and the closer it is to the network's centre. The cohesiveness of a field's nodes, representing density of its research, similarly characterises the field's potential for growth and survival. Figure 10 is a thematic map depicting soil stabilisation and swelling soil research, broken up into four sections labelled the first quadrant (Q1) through the fourth quadrant (Q4).

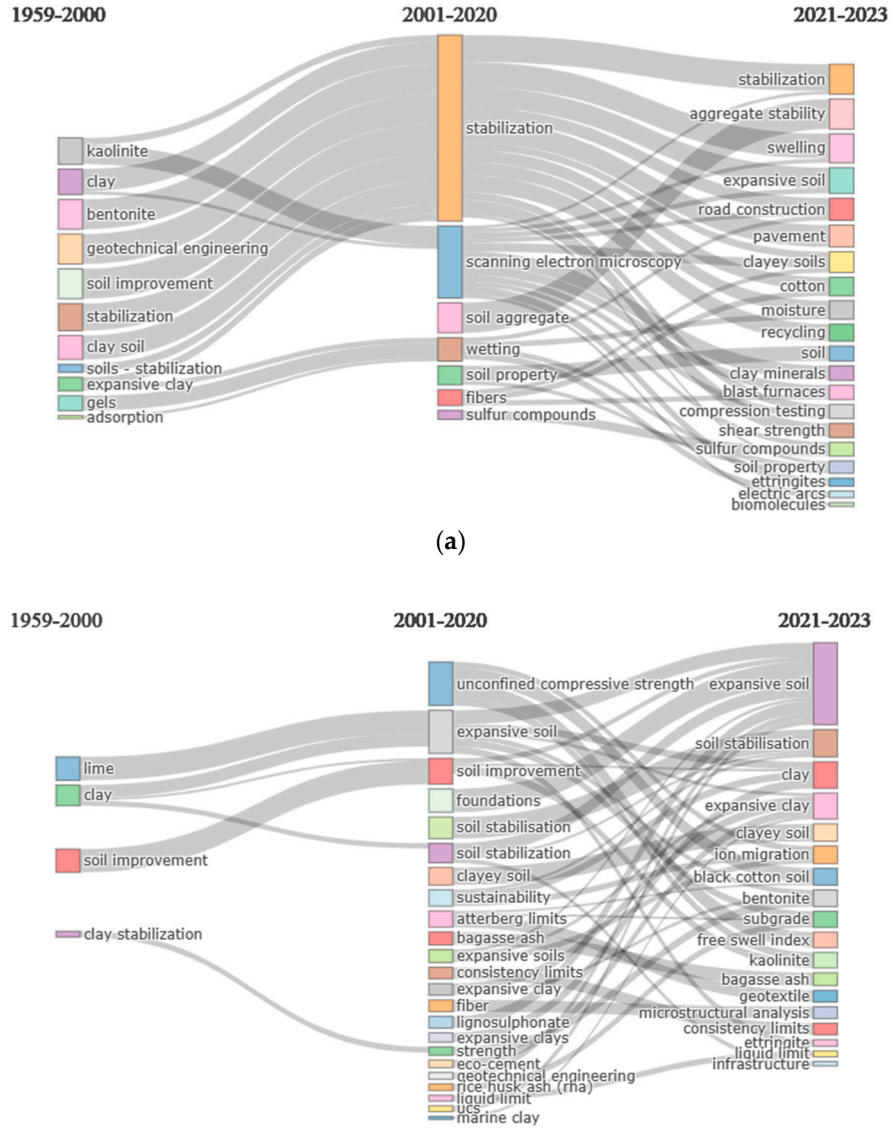

Figure 9. Thematic evolution map of keywords from 1959 to 2023 with respect to soil stabilisation and swelling soil: (**a**) keywords, (**b**) author keywords.

In a thematic map, there are four quadrants, where Q1 indicates the main theme and keywords involved, the second quadrant (Q2) shows the well-developed and very specialised domains which have a relationship with the leading theme, the third quadrant (Q3) displays the emerging themes list, and Q4 consists of transverse themes. The categories marked with Q1 in the top right corner represent the most important ones; those marked with Q4 in the bottom right corner give the secondary ones; those marked with Q2 in the top left corner provide the most specialised ones; and those marked with Q3 in the bottom left corner represent the emerging or disappearing categories. The map makes it abundantly evident that the study of a foundational problem like "soil stabilisation", which is situated between Q1 and Q4, has progressed to the point where a framework may be provided. This means that research into methods of soil stabilisation remains a top priority. As is evident in Q4, the fundamentals are crucial to the development of the sector, as evidenced by topics like "swelling", "soil stabilisation", and "expanding soils". These findings suggest that terms like "aggregate stability", "soil structure", "soil aggregate", "binders", and "tensile strength" will be prominent in the following months. The Q3's

emerging themes of "slope stability", "slope stabilisation", and "fibres reinforcement polypropylenes" appeared to be integrated towards the themes of Q4, suggesting that some of its components are fundamental and necessary for the advancement of the field of soil stabilisation and swelling soil. A thematic evaluation reveals that more work is needed to create themes like "soil stabilisation" and its connected components like "soil structure" and "soil properties", to establish more linkages with "swelling soil".

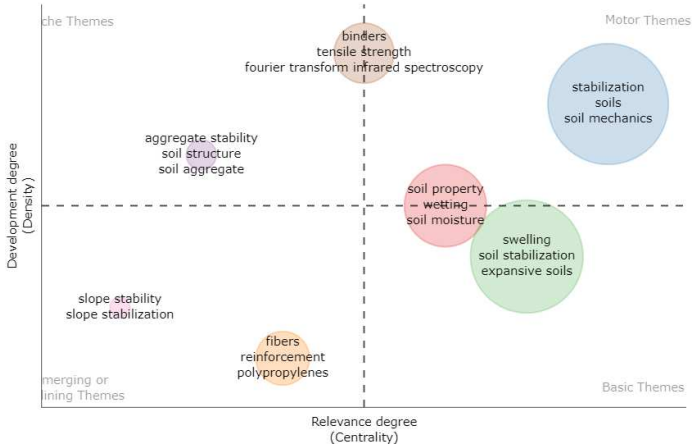

Figure 10. Thematic map of research related to soil stabilisation and swelling soil.

3.4.7. Thematic Focus on Field of Development of Engineered Soil through Soil Stabilisation

(a) Keyword analysis, co-occurrence network, and trend topics

For the study period of 1959 through to 2023, this section examines the topics and locations that have received the most attention in the research field of soil stabilisation and swelling soil. The research also aims to shed light on whether there has been a shift in the focus of debates among experts in the field. We started by looking at the frequency with which particular terms appeared. We then analysed the evolution of keywords; the most talked about subjects, the most common topics, and the most common themes in the field. Scopus often provides two sets of keywords: index keywords (those used to index articles) and author keywords (those provided by authors in articles). Identifying emerging themes and the areas of research emphasis among academics can be aided by analysing the keywords authors utilise in their publications. The keywords used in a publication's keywords section allow us to immediately determine the article's topic and scope. Figure 11 is a word cloud illustrating popular terms related to soil stabilisation and swelling soil.

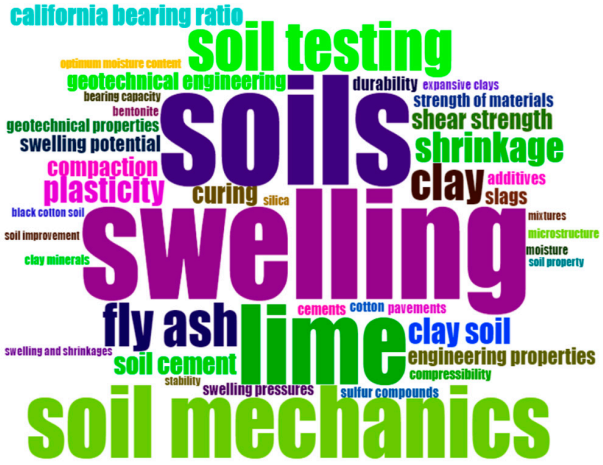

Figure 11. Word cloud visualisation with used keywords.

The above figure demonstrates the often-repeated keywords employed in this study. Keywords are used to identify an article in a publication space, as well as for many other purposes.

4. Limitations of Study and Recommendations

While this work is comprehensive, there are still caveats to be aware of when interpreting the results. Since the study only has covered the years 1959–2023 for various reasons, caution is advised when interpreting the findings. Only articles, conference papers, book chapters, reviews, and books have been considered by the authors; other types of research publications, such as informal publications, have not been assessed in this study. Furthermore, we have only investigated English-language publications [50] rather than those published in any other languages. All other uses of soil stabilisation have been disregarded in favour of the engineering usages in these investigations. Scopus is the only database we have used. However, there are others like Web of Science, www.lens.org, and Dimensions that serve the same purpose and might be utilised instead. Authors wishing to expand on this study could employ different databases and study a different period of time to develop a research article. Future work can be undertaken in this research area to analyse what sort of materials are used in stabilisation, their working mechanisms, and strength enhancement abilities. This may be compared with the research progress in this domain, which will help new researchers undertake research focussing on that material.

5. Conclusions

Soil, a readily accessible substance, is increasingly being used and sought after in the engineering and building industries. Stabilisation refers to the process of reinforcing soil, which is necessary because of its low strength as an engineering material. Soil stabilisation involves modifying the soil's physical qualities in order to boost its strength in a sustainable and reliable manner. Strengthening soil and altering its characteristics, with a focus on usage for engineering purposes, are steadily gaining impetus. In this study, we utilised the scientometric method to examine the growth of the field of "engineered soil development", the goal of which is soil stabilisation. Our data spanned the years 1959–2023. In 2021, when research interest in this field was at its highest, 150 publications were produced, making that year the most productive for publishing. We looked at how various countries, institutions, authors, and publications fared in relation to the chosen keywords. The year 2022 had the highest citation total at 3084. India was the country with the largest output, with 253 articles and 3084 citations. With only 34 and 33 publications, respectively, Iran and France ranked last. The National Institute of Technology and the Islamic Azad University published the fewest articles (17 each). Puppala AJ from India was still the most influential author on the subject of soil stabilisation and swelling soil, having published 16 documents with the highest citation count and h-index. With 612 authors, Australia had the most author associations. Swelling and stabilisation were the most popular keywords for the years 2001–2023, while Bentonite and soil improvement were the most popular keywords for the years 1959–2000. The area of soil stabilisation was seen to have matured and be capable of structuring the research field by the end of Q4. According to the results of the thematic analysis, further work needs to be conducted on developing topics like soil structure and soil characteristics. This research aimed to provide a dissemination piece explaining the current state of soil stabilisation research.

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