Scientific Review Engineering and Environmental Sciences (2023), 32 (4), 357–375

Sci. Rev. Eng. Env. Sci. (2023), 32 (4) https://srees.sggw.edu.pl

ISSN 1732-9353 (suspended) eISSN 2543-7496 DOI 10.22630/srees.5212

Received: 02.08.2023
Accepted: 20.09.2023

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A systematic review of clay shale research development for slope construction

Keywords: clay shale, systematic review, VOSviewer, slope, bibliometric

Introduction

Clay shale conditions in certain projects have a huge problem that usually occurs. Most of these issues are due to the clay minerals in shale swelling expanding too much, resulting in subsidence, cracking, and loss of bearing capacity. Due to its characteristics, which store water much better than sandy soil, clayey soil is frequently recognized as troublesome soil. These conditions induce more engineering issues because of the soil creeping. Furthermore, another study claims that because clay shale is a transitional element between soil and rock, it loses durability quickly, leading to issues in the geotechnical industry (Agrawal, Manhas & Sharda, 1993; Sharma, 1995; Sharma, 1996; Powell, Siemens, Take & Remenda, 2013; Pardoyo, Kresno, Fahreza & Maulana, 2020; Khairul & Musta, 2022; Simatupang, Alatas, Redyananda & Purnomo, 2022). Furthermore, according to Zanzinger, Koerner & Gartung (1986), unweather clay shale has a maximum cohesion of 85 kPa and an internal angle of friction of 41°.

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However, when the material was exposed to air, its shear strength reduced to zero cohesion and its friction angle was only 9 (Zanzinger et al., 1986).

The characteristic of the clay shale problem was found in several areas in Indonesia. An engineering method exercise for clay shale cutting slope was provided first by Shields in Bukit Asam locations (Shields, 1986). Another research is the water-based application that is both cost-effective and inhibitive offshore in East Kalimantan (Huadi, Aldea, Mackereth & Mukhlis, 2010). In addition, the clay shale slope investigation was also conducted on the Cisomang Bridge on the toll route between Purwakarta and Bandung (Hendry, Somantri, Febriansya & Nurhadi, 2020), as well as clay-shale cutting slope in the Karawang Area (Zhang, Wang, Zhou & Huang, 2022), Cipularang highway (Agung, Pramusadi & Damianto, 2017), Semarang, Central Java (Rahardjo, Halim & Wisanto, 2012), and Tana Toraja airport project (Gouw et al., 2016). The visual characteristic in several cutting clay shale slopes is described in Figure 1, which presents the clay shale slope on certain toll road project in Indonesia. In addition, the picture depicts the disintegration of clay shales after only a few days of exposure to the atmosphere; even if they still resemble rock, they are readily spalled off and disintegrated by applying small forces.

FIGURE 1. Clay shale slope in toll road project in Indonesia
Source: own work.

The action to solve the clay shale problem has been described in a particular area. On a problematic clay shale, a 25–37 m high retaining structure was built to support a Tana Toraja runway (Gouw et al., 2016). In addition, by adding 38 pile foundations into the existing foundation layout, reinforcement has been designed to minimize the movement of the particular pier on the Cisomang Bridge (Hendry et al., 2020). The optimal solution was the hybrid reinforced soil slope (HRSS), a combination of anchored gabion units and geogrids. The anchored gabion units were constructed from hexagonal double twisted wire mesh 8 × 10 Galmac® (Zn-Al 5%) polymer coated steel wire measuring 2.7/3.7 mm in diameter. Geogrids with an initial tensile strength of 300 kN·m^{-1} were utilized, which comprised of high-tenacity polyester yarn tendons encased in polyethene (Gouw, 2018). However, the information on the further topic related clay shale study has not been presented in clay shale slope stability research.

Several article issues describe the clay shale performance. Table 1 presents published review studies about clay shale. Table 1 divides the categories into five areas: case study, rock mechanics, clay mineralogy, slope stability, and bibliometric analysis. A "YES" means the article examines certain criteria, and "NO" vice versa. The percentile of review articles shows most of these describe rock mechanics in clay shale, which reaches 100%. Moreover, the case study analysis is the second topic

TABLE 1. Summary of review articles and published research on clay shale

Year	Reference	Examined case study	Discussed rock mechanics	Discussed clay mineralogy	Analysis for slope stability	Provided bibliometric review
2000	Einstein, 2000	YES	YES	NO	NO	NO
2003	Picarelli et al., 2003	YES	YES	YES	NO	NO
2003	Nomura, 2003	YES	YES	NO	YES	NO
2004	Mesri & Shahien, 2004	YES	YES	NO	YES	NO
2009	Bonini, Debernardi, Barla & Barla, 2009	YES	YES	YES	NO	NO
2014	Al-Arfaj, Amanullah, Sultan, Hossain & Abdulraheem, 2014	NO	YES	YES	NO	NO
2016	Herbosch, Liégeois & Pin, 2016	YES	YES	YES	NO	NO
2021	Mo et al., 2021	NO	YES	YES	NO	NO
2021	Sharifigaliuk, Mahmood, Rezaee & Saeedi, 2021	YES	YES	NO	NO	NO
2021	Rosly, Mohamad, Bolong & Harith, 2022	YES	YES	NO	YES	NO
2022	An, Zagorščak & Thomas, 2022	NO	YES	YES	NO	NO
2022	Pingquan et al., 2022	NO	YES	YES	NO	NO
2022	Jinhua et al., 2022	YES	YES	NO	NO	YES

Source: own work.

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with 76.9%. The clay mineralogy and slope stability are the third and fourth levels, with 53.8% and 23%, respectively. Lastly, the article that utilizes bibliometric analysis is the lowest topic, under one-tenth (7.69%).

This review study summarizes the published research for clay shale beginning in 1980 and presents a bibliometric analysis to identify the published studies based on year and country, and provides various research prospective in particular maps using the VOSviewer program.

Methods

Bibliometric review by sequence

The overview organizes the body of research on clay shale structures into categories and provides reinforcement for clay shale slope design. The best technique for ensuring the best quality of the reference lists is to do a systematic literature evaluation (Snyder, 2019) by performing a bibliometric analysis (Morrisey, 2020; Donthu, Kumar, Mukherjee, Pandey & Lim, 2021). The most recent research findings from publications that have been published and conference proceedings linked to clay shale have been statistically evaluated in a bibliometric assessment. In addition, the VOSviewer software was successfully analysed in the civil engineering study (Yu, Xu & Antuchevičiene, 2019; Wang, Xu, Ge, Zavadskas & Skačkauskas, 2020; Aristizabal, Lara, Payares & Alzate, 2021; Mulyawati & Ramadhan, 2021; Videras Rodríguez, Melgar, Cordero & Márquez, 2021; Shahbazi, Elahi & Khalili, 2022) and other topic research (van Eck & Waltman, 2010; van Eck & Waltman, 2017; Nandiyanto & Al Husaeni, 2021; Ding & Yang, 2022; Kuzior & Sira, 2022; McAllister, Lennertz & Atencio Mojica, 2022; Soegoto, Soegoto, Luckyardi & Rafdhi, 2022; Tamala, Maramag, Simeon & Ignacio, 2022). Figure 2 presents the method of bibliometric analysis.

First step: Entering keywords in two groups. For a list of the groups (see Table 2).

Second step: Collect electronic resources from the Scopus search engines.

Third step: The bibliometric analysis identifies the published research for clay shale by year and nation. Then, use VOSviewer to generate a bibliometric map to show the most recent developments in clay shale research and clay shale reinforcement slope.

Fourth step: Extraction of data from the third step, including the goals of the study, the procedures followed, and any conclusions that could be relevant for further research.

Fifth step: The bibliometric analysis identifies the published papers for the clay shale research by year and nation. Then, to display the most recent trends linked to the issue, generate the bibliometric map using VOSviewer.

Sixth step: Data extraction from the fifth step, which summarizes the objectives of the study.

Seventh step: Generate discussions for bibliometric evaluation.

Eighth step: This study's concluding statement.

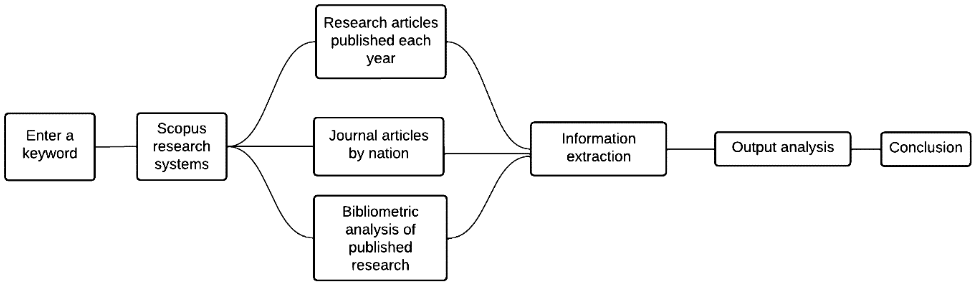

FIGURE 2. The bibliometric review method
Source: own work.

The data was collected in the Scopus website system on 1 May 2023. Table 1 shows the various keyword for this study. The first is "clay shale OR clay-shale", with the output reaching 597 articles, while another specific keyword, such as "clay--shale, slope", generates 89 articles, and the last is "clay-shale, landslide", with 67 items.

TABLE 2. Generated keywords for this review

No	Source	Keyword	Number of articles
1	Scopus	"clay shale OR clay-shale"	597
2	Scopus	"clay-shale, slope"	89
3	Scopus	"clay-shale, landslide"	67

Source: own work.

The Scopus is used as a database version because of the open access factor. Moreover, the Indonesian regulation utilized the Scopus index as the key factor of the institutional performance index. An organization must decide based on institutional needs if it can only afford a systematic review (Burnham, 2006).

The timeline for searching for relevant documents began in 1980 as the published year (Hobson, 1980). The measurement of the published research from 1980

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to 2022 was the main goal of the search. The inquiry also included the most recent 5 years of records, from 2018 to 2022. Review articles, research articles, conference proceedings, books, and book chapters that were written and published in English were all included in the search criteria. The file format for these digital resources is Research Information System (RIS), which makes it possible for citation management software to combine data with it.

Clay shale published research by year

The output of annual publication in the keyword "clay shale OR clay-shale" is shown in Figure 3. According to Figure 3, the oldest article was in 1980 and generally increased through the period's end. Although the fluctuating condition occurs several times, the average use of a trendline as a control that shows the value of the rise is $R^2 = 0.843$.

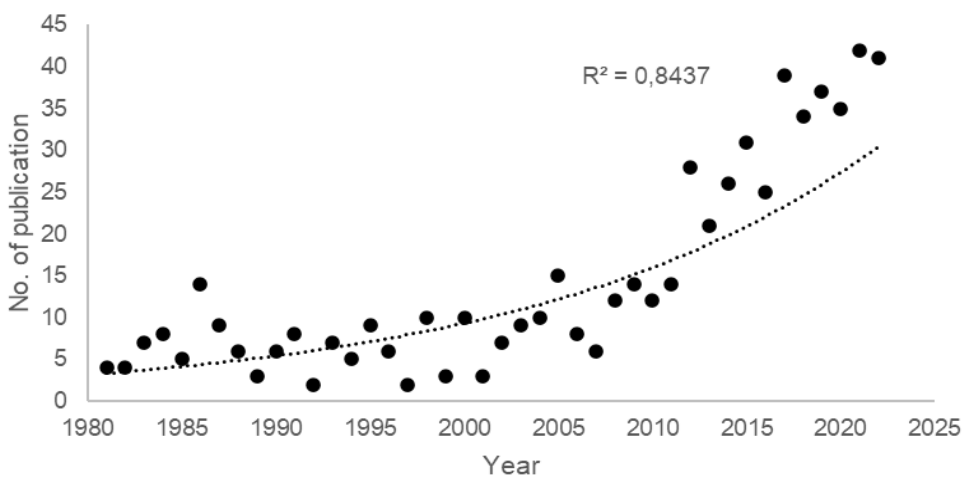

FIGURE 3. Research for clay shale by year of publication
Source: own work.

In terms of other keywords, namely "clay-shale, slope" and "clay-shale, landslide", they have also been described in Figure 4. The result shows a similar trend to the previous one, the increasing value throughout the year. However, these 2 categories have different specific trendlines, depicted in R^2 0.5275 and 0.3992. The lower R^2 because the total article that smaller than the keyword "clay shale OR clay-shale".

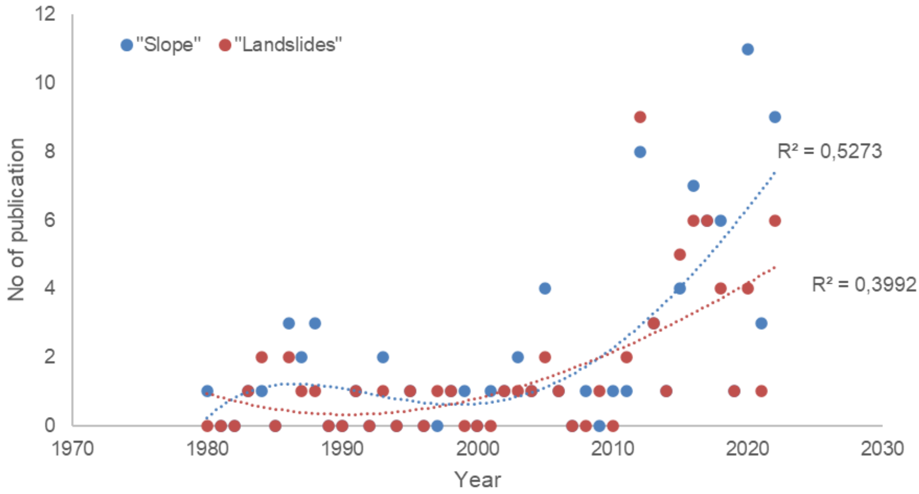

FIGURE 4. Research for clay shale by year of publication with specific keyword
Source: own work.

Clay shale published research by country

Figure 5 shows the bibliometric evaluation in bar chart style and lists the top 14 area of origin for the papers from the 1980–2022 collection that were searched.

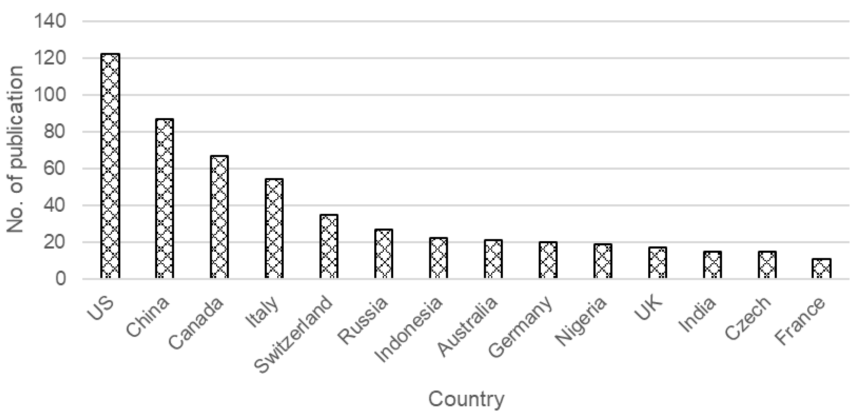

FIGURE 5. Published article based on country with keyword "clay shale"
Source: own work.

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In general, the highest publication is from the United States (US) with 122 articles, and France has ranked fourteen with 11 publications. The number 14 is picked because of the big gap between the fifteen 15th range rather than the total number of another level. Another country is China with 87 items, Canada with 67 publications, Italy is 54 items, Switzerland with 35 publications, Russia with 27 numbers, Indonesia is 22 items, Australia is 21 items, Germany with 20 publications, Nigeria is 17 items, the United Kingdom 17 publications, India is 15 items, and Czech with 15 items.

The analysis of another keyword produces different outputs based on the country published. The resulting detail of the keywords "clay-shale, slope" and "clay-shale, landslide" have presented in Figure 6. The highest article was published in Italy and was in a different location from the previous keyword, "clay shale OR clay--shale," with 26 and 27, respectively. Canada is the second level, with 16 and 8 items, respectively.

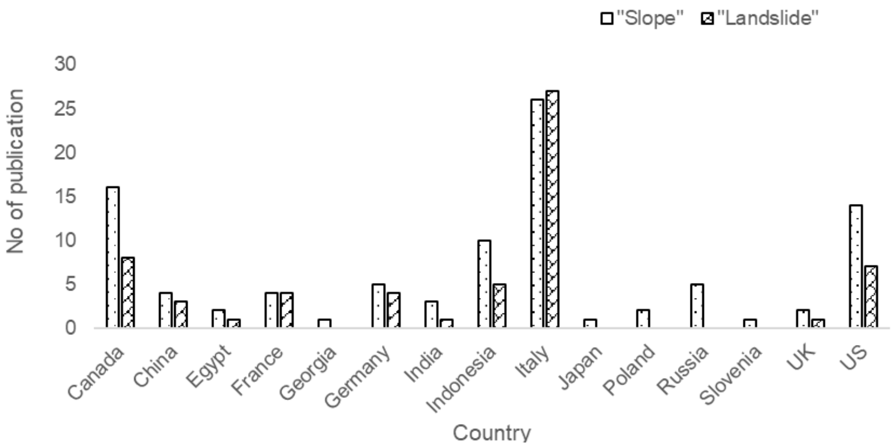

FIGURE 6. Published article based on country with different specific keyword
Source: own work.

Moreover, the United States moved three positions with slope keywords in 14 articles and 7 ones for the landslide category. Indonesia is the next level which describes the large gap among the 5–15 ranks with 10 and 5 publications. In addition, in two different keywords, the process shows the significant output for Georgia, Japan, Poland, Russia, and Slovenia that only have the keyword "clay-shale, slope" in their clay shale publication.

Map of published research for the clay shale research

The bibliometric analysis using VOSviewer, based on the Scopus index from 1980 to 2022, has been described in Figure 7 with 5,432 keywords and 308 meet the threshold. The input keyword is "clay shale OR clay-shale". There are 5 clusters with different color.

First cluster presents the big keyword "clay shale" with blue color. This topic is linked with soil mechanics, foundations, and rocks. Furthermore, this category is connected with clay minerals, rock mechanics, and landslides.

Second cluster is green in color with the large topic being rock mechanics. This scope interconnects with anisotropy, excavation, and deformation. Moreover, this scope is connected with clay minerals and clay shale.

Third cluster is red in color with the theme of clay minerals which is linked to clay shale and rock mechanics. This section is interconnected with porosity, pore structure, and silica.

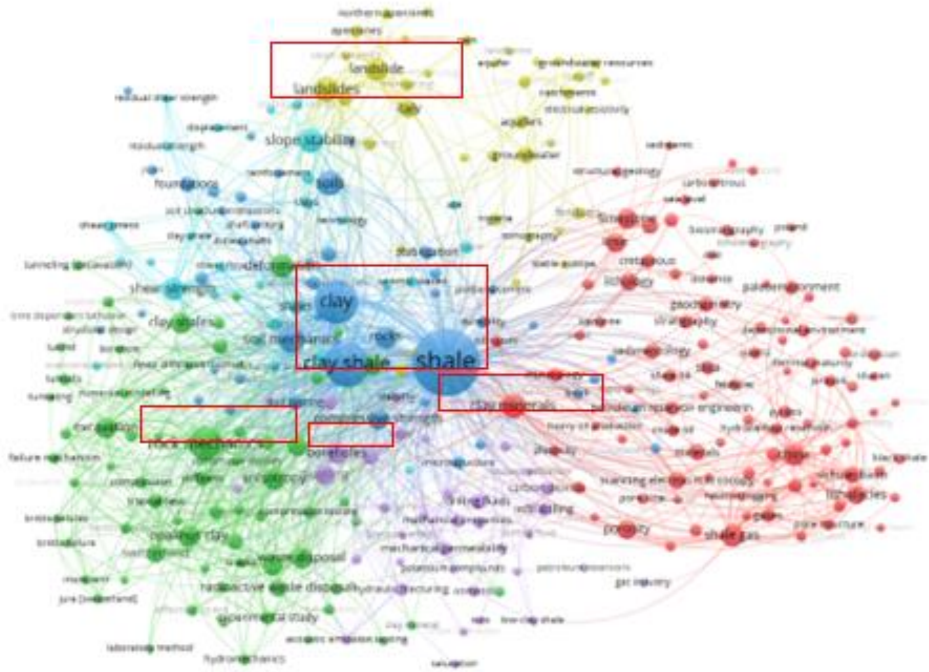

FIGURE 7. VOSviewer's output map of published clay shale research
Source: own work.

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Fourth cluster is landslides with a yellow presentation. This topic is interconnected with rain, groundwater, and hydrogeology. In addition, this category is linked with clay shale only. Although it connects with deformation, there is no relationship along clay mineral, swelling and also rock mechanics.

Fifth is purple color with big theme is swelling. It is interconnected with permeability. Furthermore, this part is linked to clay shale and rock mechanics. However, there is no connection with the other section, namely landslides and clay minerals.

Map of published research for the clay shale slope research

The output of VOSviewer investigation with keyword "clay-shale, slope" has been depicted in Figure 8. According to Figure 8, the cluster is divided into 3 criteria.

The first category is green, with clay shale being the main topic. It is interconnected with slope failure, stability analysis, and rock mechanics. Meanwhile, the clay-shale theme is linked to landslide and slope stability. However, the slope

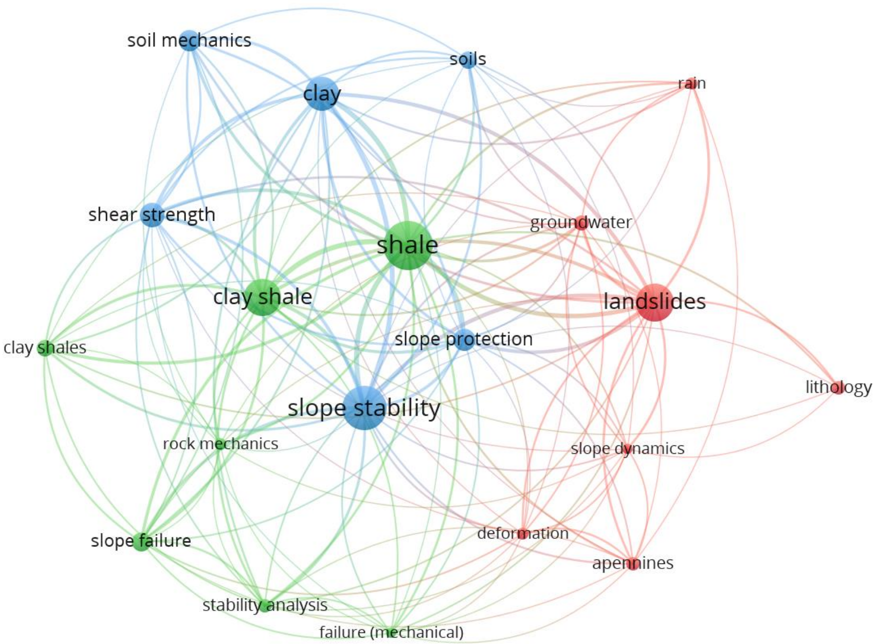

FIGURE 8. VOSviewer's output map of published clay shale slope research
Source: own work.

dynamic and deformation are excluded from this description. The second is a red color, with the big topic being landslides. It includes slope dynamics, deformation, rain, and groundwater. Also, this general topic is connected to clay shale and slope stability. The last color is blue, with the topic being slope stability related to all subcategories in this map.

Extrapolation of data from published research on clay shale

The collection of information from the most recent studies is accomplished by summarizing the main objectives, useful procedures, and significant findings that may be applicable to future research investigations on clay shale. Table 3 provides a summary of the most recent studies published from 2020 to 2023 that contained the keywords "clay shale" and combined by "landslide" and "slope".

TABLE 3. Generated keywords for this review

Year	Detailed description of the study	Keyword
2023	This study proposed a methodology and evaluate the outcomes. Within a weathering clay shale and undisturbed clay shale, an interface direct shear test was conducted until its residual state. Using a two-day wetting-drying cycle, the weathering condition of the bottom clay shale is accomplished by soaking and drying the bottom of the sample. Results revealed dispersed values and distinct behavior for wet and dry conditions as weathering days increase. The wet condition increased cohesion, increased the average stress ratio, and decreased the friction angle. The lack of hydration decreased cohesion, increased friction angle, and increased the average stress ratio (Sagitaningrum, Kamaruddin, Nazir, Soepandji & Alatas, 2023).	"clay-shale, slope"
2022	A series of triaxial compression experiments were performed on reconstituted clay shale specimens with normal consolidation. On the basis of laboratory results, an empirical correlation for the secant entirely softened friction angle was derived for clay compositions with a plasticity index between 10 and 250% and an effective normal stress between 10 and 700 kPa. Stability analyses of 63 first-time collapses of slopes in 38 geologic materials were used to investigate the field utilization of a secant totally softened friction angle. There are 45 slope failures with a portion of observed slip surface at residual condition and the back-scarp generating fully softened shear strength, and 18 slope failures with the entire observed slip surface being fully softened (Mesri, Wang & Kane, 2022).	"clay-shale, slope"
2022	In the Apennines, tectonized clay shales are prominent. The poor mechanical properties of these structurally complex materials cause their sloping deposits extremely unstable. In fact, small mountain communities and the infrastructure that services them are constantly at risk of becoming ineffective, requiring high maintenance costs. The analysis of the effects of slope movements on structures and individual artifacts is an especially difficult task that requires specific and targeted approaches. This paper examines the interaction between the unsteady movement of slopes in tectonites clay shales and tunnels in a number of cases (Comegna & Picarelli, 2022).	"clay-shale, landslide"

TABLE 3 (cont.)

2021	Investigations conducted primarily in the United Kingdom and Italy indicate that the accumulation of significantly positive excess pore pressures induced by the processes of undrained loading is the cause of these specific slope movements. In the case of tectonized clay shales, this interpretation warrants further investigation; in fact, given the structure and stress background of such overconsolidated deposits, the rise of high certain excess pore pressures is not an expected consequence of undrained loading. This research attempts to interpret this not-so-minor aspect of the issue by providing experimental data that emphasize the high susceptibility of these soils to dramatic degradation due to chemistry changes in the pore fluid (Picarelli, Di Maio & De Rosa, 2021).	"clay-shale, slope"
2021	This study presents the findings of an extensive examination of the sluggish movements of two underground earthflows in the tectonized clay shales of the southern Apennines. The accumulated movements have caused extensive damage to structures and infrastructure over the years, resulting in significant social and economic costs. Since 2005, depth and superficial displacements, as well as pore water pressures, have been monitored; in some areas of the slope, inclinometers have been used to monitor displacements for roughly three decades. Utilize satellite interferometry to monitor the area. To mitigate this issue, the most granular analysis was performed on satellite data pertaining to regions where displacements and paths are definitely identified through inclinometers and GPS. The data confirmation allowed for the confident application of remote sensing results over a larger region. Consequently, images obtained by the COSMO-SkyMed satellite structure, supplemented by the European remote sensing satellites (ERSs) data sets and Envisat data, enabled an analysis of the kinematic history of the urbanized area, even though inclinometer displacement series were only available for limited periods (Vassallo et al., 2021).	"clay-shale, landslide"

Source: own work.

Discussion

The whole research about clay shale analysis is spread around the world. America, Europe, and Asia are the continents that dominate clay shale research. However, the landslide and slope issues in the clay shale subgrade are presented in different countries. Although the United States does the highest research on clay shale, the study about the slope of clay shale needs to be shown in this area. Italy has the biggest number of publications related to the clay shale slope. This result is suitable because Italy has the Apennines area that has a huge issue with clay shale, which provides research about clay shale slope investigations in the southern and northern Apennines (Dondi, 1999; Veniale, Delgado, Marinomi & Setti, 2002; Di Leo, Dinelli, Mongelli & Schiattarella, 2002; Picarelli, Urciuoli, Mandolini & Ramondini, 2006; Mongelli, Critelli, Dinelli, Paternoster & Perri, 2010; Cavalcante, Belviso, Piccarreta & Fiore, 2014; Bayer, Simoni, Mulas, Corsini & Schmidt, 2018; Costanzo, d'Onofrio & Silvestri, 2019; Smeraglia et al., 2021;

Squarzoni, Bayer, Franceschini & Simoni, 2020; Veniale, Pellegrino, Marinomi & Setti, 2023).

In terms of year of publication, 2 research studies about clay shale and clay shale slope have a similar trend. The number of articles increases slightly in the first year through 2010. In addition, after 2010 until the end of the period, this study goes up rapidly. These conditions happen because of the development of technology and system that support the clay shale research and investigation. Furthermore, the need for an infrastructure construction project leads the engineer to deal with the clay shale issue as a subgrade site.

The output of the VOSviewer analysis has shown 5 clusters with different themes. The topic of the landslide has few links with other clusters, such as clay mineralogy and rock mechanics. Meanwhile, the strong link is only in deformation, slope stability, and clay shale. These circumstances present a gap among these categories and require further study.

Regarding the result of the clay shale slope from VOSviewer, the output shows the domination of links among all clusters. Three clusters have been depicted in this analysis. In addition, the wide gap is described as a link between slope dynamics and other topics. This output means potential research is required to conduct dynamic force issues for clay shale slope study.

Conclusions

the article examines the published research on clay sale and clay shale slope study using bibliometric analysis. All of the results suggest the need for further investigation to fill the knowledge gap regarding clay shale, landslide, and clay mineralogy. Moreover, the clay shale slope has presented the need for further research about dynamic force and its deformation through clay shale slope analysis.

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Summary

A systematic review of clay shale research development for slope construction. The issue of stability controlling cutting slopes is particularly important in clay-shale slopes, a typical expanding sedimentary layer with poor engineering geological conditions and mechanical characteristics. Therefore, research on the causes of failure and remedies for clay-shale cutting slopes is required to serve as an overview for handling and preserving clay-shale slopes in identical conditions. However, the trusted information about the need for further related clay shale research and clay shale in slope stability has yet to be specifically presented. This review study summarizes the published research for clay shale beginning in 1980, presents a bibliometric analysis to examine the published research based on year and country, and provides various study trends in cluster diagram using the VOSviewer program. The analysis also summarized some key goals, effective methodology, and significant findings from the most recent studies to extract information from them that would benefit future research. In conclusion, the results show the need for developing research to fill the knowledge gap regarding clay shale, landslide, and clay mineralogy. In addition, the clay shale slope analysis has revealed the need for additional research into dynamic force and its deformation.