Kochi Chapter

Indian Geotechnical Conference
IGC 2022
15th – 17th December, 2022, Kochi

A systematic Review on Application of Electrokinetics in Treatment of Problematic Soils

C. Shukla[1][0000-0001-8573-7009] and B.K. Pandey[2][0000-0001-8043-3815]

[1] Department of Agricultural and Food Engineering, Indian Institute of Technology Kharagpur, Kharagpur 721302, West Bengal, India.
[2] School of Civil Engineering, Shri Mata Vaishno Devi University, Kakryal, Katra, 182320, Jammu and Kashmir, India.
balbirpandey123@gmail.com

Abstract. The geotechnical and geoenvironmental issues related to polluted and low strength soils requires special remediation and stabilization technique. The application of electrokinetics has gained wide recognition as a sustainable soil treatment method in the recent years. Hence, deliberating the subjects and expanding collaborative linkages are essential for the future researches. In this study systematic review on application of electrokinetics in treatment of problematic soil on the basis of existing research trend has been presented using a freely available software VOSviewer. The analysis result shows that total 1562 articles were published across the world. The results also confirms that publication output has increased significantly in the last 5 years, which accounts for roughly 37% of over-all publications. The researchers from China, USA, Spain and South Korea contributed approximately 60% of total publications globally. Among the most prominent top 15 authors, approximately 40% were from Spain, followed by 13% each by the USA and China.

Keywords: Electrokinetics, Citations, Publication data.

1 Introduction

The substantial growth in the world population in the last decades raised serious concern for the infrastructure and food security requirements. As the suitable land for growing the food grains and meet the demand of infrastructure is fixed therefore, there has to be alternate land available for the intended purpose. The soils of selected alternate sites may be problematic in nature due to presence of contaminants [1-2], low shear strength [3-4] and high-water content [5]. The presence of contaminants may pose grave danger to human health and the ecology. In order to remove the soil contaminants, various methods such as thermal desorption, bio-remediation, soil washing etc. widely used [6]. The use of electrokinetics in the soil treatment is gaining much importance due to its ability to remove different kinds of pollutant in a sustainable way [7-9].

Further, when soil with low strength and high-water content is met during infrastructure construction, it requires modification in the properties of the soil to suit its structural safety and serviceability requirement. There are numerous soil modification techniques that are employed to enhance the strength [3-4]. The application of these methods lowers the water content and risk of differential settlement, increases the

consolidation process, modify the soil structure and clay mineralogy, along with increasing the load carrying capacity [10-11]. Nevertheless, in few occasions the site condition requires special attention owing to very high-water content, which require special treatment techniques. Therefore, electrokinetics may be applied in situation which demands removing contaminants and lowering the water content simultaneously [3, 12]. Extensive study has been conducted to understand the technique of electrokinetics during the process of soil treatment [5, 13-14]. The process of water movement and elements influencing the behaviour of the electrokinetic treatment are extensively studied by Casagrande [15], Shang [16] and Malekzadeh et al. [17]. Similarly, the application of electrokinetics for bioremediation of organic contaminant have been studied by Gill et al. [18]. However, no studies has been conducted to understand overall research status on use of electrokinetic in soil remediation, soil treatment and dewatering from a bibliometric perspective. The bibliometrics has been comprehensively engaged in exploring the research hotspots and growth trends of a specific research topic such as microbial fuel cell [19], soil nutrients [20] other research topics.

The primary aim of this paper is to examine research trend on the use of electrokinetics in the treatment of problematic soils on the basis of bibliometric characteristics. The potential bibliometric networks maps that are part of the constructed database were analyzed using freely available software VOSviewer. This paper will serve as a base for early career researchers who are new to this field in discovering the potential and opportunities for future research.

2 Methodology

A methodical strategy to identify worldwide research trends in a specific field based on the outputs of an academic publication database is the bibliometric survey study. This method distinguishes bibliometric analysis papers from review papers, which are primarily designed to address the most recent advancements, difficulties, and potential future directions of a particular issue..

2.1 Data Source and Search Strategy

The data survey was performed using Scopus database on 14 February 2022. The principal theme in this investigation was research publications on application of electrokinetics in stabilization, and remediation of problematic soils. The documents from year 1960 to 14 February 2022 were searched and downloaded as CSV file. The query string used for the search in the Scopus database was: TITLE-ABS-KEY ((electrokinetic AND remediation AND of AND soil) OR (electrokinetic AND consolidation AND of AND soil) OR (electro-dewatering) OR (electro-osmotic AND treatment AND of AND soil) OR (electrokinetic AND geosynthetics)). This query sequence led to total 1562 published documents. Out of the total number of documents received, journal articles made up the bulk (1190), followed by conference papers (247), review articles (69), book chapters (35) and other documents (miscellaneous).

2.2 Bibliometric Networks

The bibliometric networks of nations, authors, keywords, documents, and citations of the searched 1562 articles were created and predicted using a free software Programme called VOS viewer (Eck and Waltman 2010) (version 1.6.17). The network components such as author, countries, citation, co-author or keywords to name a few were included in this study. Further, A link or a connection between two items can also exist between any pair of items. The strength value of each link suggests that higher is the strength value stronger is the relationship. Further, each item with their links and corresponding link strength are clubbed into a cluster. For instance, in the case of co-authorship examination, the totals of articles co-authored by two associated nations is indicated by the link strength between countries. The overall link strength, on the other hand, shows the strength of co-authorship links with other nations.

Co-authorship Investigation

Using VOSviewer, co-authorship research was conducted on countries with at least 10 documents. In light of this requirement, only 29 of the total 65 countries fall inside this range. Furthermore, 10 published documents by a given author were maintained as the selection criteria for the co-authorship analysis of authors, and taking this into account, 84 of the total 2898 authors fit the requirement. Only 66 of them, though, were linked to one another.

Co-occurrence Study of Keywords

In the study of the co-occurrence of keywords, 8816 keywords were referenced in all 1562 articles. The least 25 times that a certain term must appear in the analysis in the VOSviewer was maintained. Only 227 terms actually meet the criterion as a result.

3 Result and Discussions

3.1 Research Growth and Publication Productivity

The data of published literature based on field implementation and experimental works executed in laboratory reveals that using electrokinetics for soil treatment is beneficial and encouraging. As noticed from Fig. 1, a total of 1562 literature articles were published in the last 6 decades. The first literature dated back to early 1960 by Belluigi (1960) and there was no further work undertaken till 1966. As noticed from Fig. 1, the application of electrokinetics has not gained significant importance till 1990, afterwards the research in this area has increased significantly. Further, during the period of early 2000 to 14 February 2022, approximately 90% of the total articles were published. Compared to last decade (i.e., 2000-2010) the number of publications in the current decades has increased approximately twice. Further, the number of annual publications has increased rapidly in the last five years which accounts for approximately 37% of the total publications. Hence, it is predicted that the yearly publication will further increase with the development in the technology and area of application. Nevertheless,

the majority of these literature are not free to read, and the researcher requires subscription to have access to the info included in these articles. It is stated that if a work is published in an open access journal, it is expected to earn more citations.

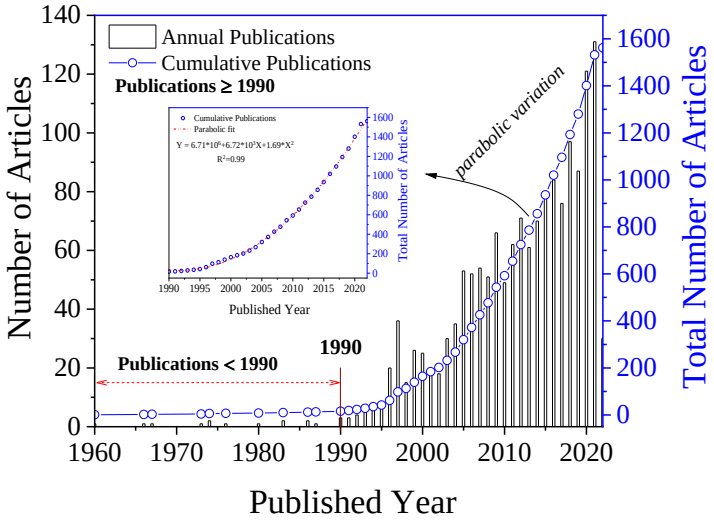

Fig. 1. The yearly and total numbers of articles on electrokinetics remediation between 1960 until February 2022

The application of electrokinetics in stabilization and remediation of problematic soils are is widespread and numerous organizations/teams are working devotedly in this domain. The analysis of the keywords, as shown in Fig. 2, reveals that the most frequent keywords were soil pollution (789 occurrences), remediation (665 occurrences), soils (654 occurrences), electrokinetic remediation (602 occurrences), electrodynamics (562 occurrences), and others. Further in the last five years the area of application has tremendously increased. Further, it was observed that the prominent research domain was from Environmental Science (899 documents) background followed by Chemistry (392 documents), Engineering (334 documents), Chemical Engineering (324 documents) and Earth and Planetary Science (272 documents). Indeed, the application of electrokinetics for various purposes in soil is a multidisciplinary area where a total of 14 articles were published.

The searched literature as per scopus data base were published in ten languages, according to the findings English (1442; 92.31%) was frequently used language. The Chinese (94; 6.40%) language came distant second followed by other languages (20; 1.29%) such as Spanish, French, Japanese, Korean, German, Italian, Persian, and Portuguese. However, if a publisher submits a work in a language other than English for Scopus indexing, then also the title and abstract of the article should be written in English.

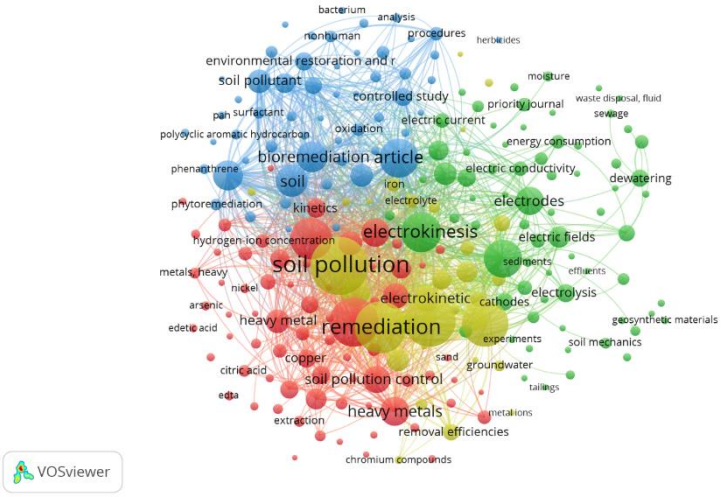

Fig. 2. Bibliometric network of co-occurrence of author keywords with overlay visualization mode. Criteria set for co-occurrence of author keywords is 25.

3.2 Leading Countries and Collaborations

Table 1 shows the top 10 countries in terms of their publication in the mentioned field. As it can be seen that China being world's most populated and second largest economy (in terms of GDP) published highest number of documents compared to other top nations in the list. It accounts for a total of 475 documents which share around 30% of the total publications. However, United States contributed approximately half of the publication compared to China. The third most productive nation in terms of publications is Spain which accounts for approximately 9.5% of the total publication.

Table 1 Table showing top10 countries in terms of total publications and their related details

Country	Publication	Percentage of Total	GDP Ranking (IMF 2021)
China	475	30.40	2
United States	240	15.36	1
Spain	147	9.41	14
South Korea	107	6.85	10
United Kingdom	83	5.31	5
Taiwan	65	4.16	21
Canada	62	3.97	13
Australia	56	3.59	9
India	49	3.14	6
Iran	47	3.00	8

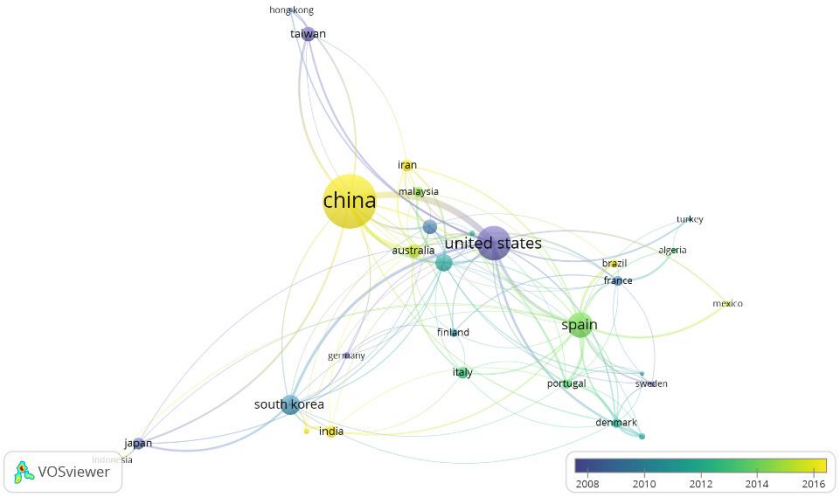

Fig. 3. Overlay visualization of bibliometric network of the countries constructed on co-authorship

Subsequently, from a country's standpoint, co-authorship of publications suggests a reasonably significant relationship between the United States and other countries (Fig. 3). Total seven clusters are noted, with Spain having the most notable cluster (Cluster number 5). The cluster 5 in which Spain is at center has total 22 links with all the prominent nations except China. The second-most important cluster is cluster number 4, where the USA is the emphasis nation and there are 240 papers and 20 links. When compared to the Spain cluster, the USA cluster has 1.46 times the link strength. Although China has highest number of documents their link and link strength are significantly lower compared to that of leading countries like Spain and the USA. However, the cluster 1 emerging nations, including India, have a total of 6 links with a link strength of 14 and 49 documents. As a result, co-authorship of documents is a little more global, but as one might anticipate, there are still some important regional connections.

3.3 Prominent Researchers, Top Institutions and Their Collaborations

Table 2 shows top 15 prominent researchers based on their total publication in the mentioned research area. The table also gives the current affiliation of the prominent researchers and year of their first publication in this field along with their country, total citation and h-index. As it can be seen from the table that out of top 15 authors, six authors belong to Spain. The most prominent Institution of Spain is ‘Universidad de Castilla-La Mancha’, which is publishing large number of valuable research studies on electrokinetics in soil treatment. The second and third most prominent researchers in the list belong to the USA, and China, as they have two authors each in the list. Among the prominent researcher Reddy, K.R. of Department of Civil and Materials Engineering, University of Illinois at Chicago, USA has maximum publications and citations

equated to others. He has total 60 publications with total 3192 citations. His first document was published as first author in the year 1996. The second and third authors in the list are Rodrigo, M.A. and Cañizares, P. from Department of Chemical Engineering, Universidad de Castilla-La Mancha, Spain. Both of them published their first article in the year 2007, Cañizares, P. published as first author whereas Rodrigo, M.A. was the co-author. The total number of publications of Rodrigo, M.A. and Cañizares, P are 52 and 46 with the total citations of 1326 and 911, respectively.

The minimum number of publications per author was then set to 10, and out of the total of 2898 writers, 84 authors met the criterion in order to obtain the co-authorship network map of authors using the VOSviewer, as shown in Fig. 4. Interestingly, only 66 of these authors were connected with each other having total link and link strength of 274 and672, respectively. These authors have been kept in total nine clusters, for example, cluster 1 which consists of authors like Guo, S.; Wu, B.; Zhang, L.; and others and labelled are labelled in red color. Whereas, cluster 4 consists of authors like Reddy, K.R.; Cameselle, C. and others and labelled in yellow color. Similarly, Fig. 6 shows the co-citation study of the authors having citations greater than 50, the link illustrates the connectivity of authors created on their citations. As per the set criteria only 459 authors meet the threshold. These authors are clubbed together in six clusters having total link and link strength of ~89 thousand and ~24 lakh, respectively. The different colors in the Fig. 5 indicates different clusters. The scholars listed in table 2 and network map of Fig. 4 and Fig. 5 are the prominent authors in this field and their research must be followed for latest happening, science upgradation and innovation in this field.

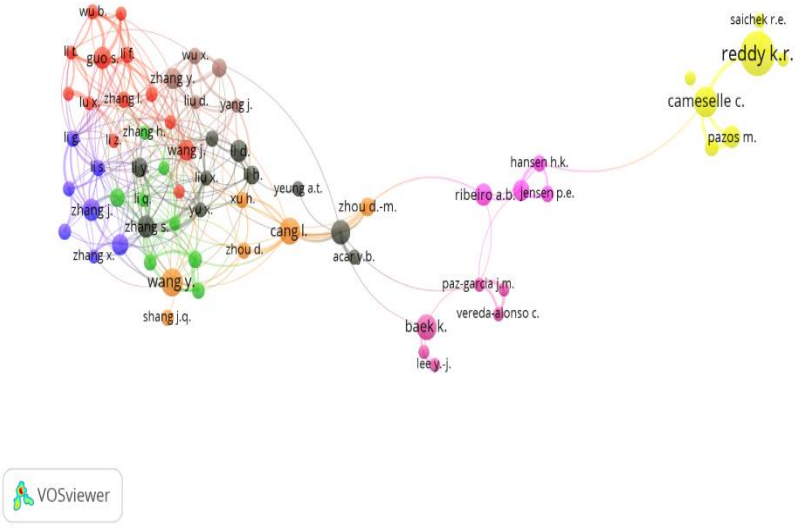

Fig. 4. The bibliometric link of co-authorship investigation of authors

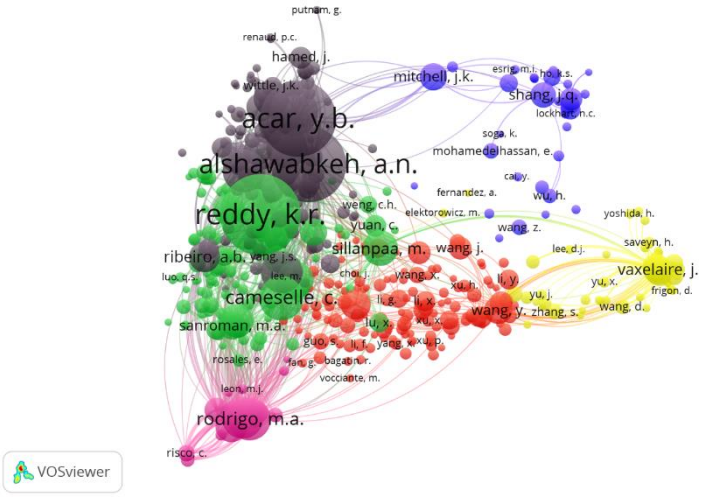

Fig. 5. Co-citation study of the authors having citations greater than 50, the network depicts the relationship between citations based on authors.

Table 2 Table showing top 15 authors in terms of their total publications and their related details

Authors	Total Publications	Citation	Publication Year	Country of Affiliation
Reddy, K.R.	60	3305	1996#	USA
Rodrigo, M.A.	52	1469	2007*	Spain
Cañizares, P.	46	1006	2007#	Spain
Cameselle, C.	33	1343	1999*	Spain
Cang, L.	28	1056	2004*	China
Baek, K.	26	1036	2005*	South Korea
Navarro, V.	24	506	2014*	Spain
Alshawabkeh, A.N.	23	2253	1992#	USA
Sillanpää, M.	22	1083	2001*	Saudi Arabia
Pazos, M.	21	703	2006#	Spain

4 Conclusions

The study has provided a summary on use of electrokinetics in stabilization and remediation of problematic soils. The summary is based on 1562 published articles between year 1960 to 14 February 2022 extracted from the Scopus database. In the last five years, publication growth has been rapid, and it is expected to continue. It is observed that the countries like USA, China, Spain and others having huge number of publications, also have robust international associations. However, countries like India have a

long way to go in this regard. Some authors are most prominent authors in terms of their total publications, citations and linkages. These authors may provide a prospect for budding researchers to broaden their research collaborations. Further, the paper also provides various challenges related to field implementation of electrokinetics and probable remedial measures. At the end, this study provides directions for the future research and suggests that coupling of electrokinetics with renewable source and other soil stabilization and soil remediation techniques.

References

1. Reddy, K.R., Ala, P.R., Sharma, S., Kumar, S.N.: Enhanced electrokinetic remediation of contaminated manufactured gas plant soil. Engineering Geology 85, 132–146 (2006)
2. Pedersen, K.B., Jensen, P.E., Ottosen, L.M., Barlindhaug, J.: The relative influence of electrokinetic remediation design on the removal of As, Cu, Pb and Sb from shooting range soils. Engineering Geology 238, 2–61 (2018).
3. Pandey, B.K., Rajesh, S.: Enhanced engineering characteristics of soils by electroosmotic treatment: an overview. Geotechnical and Geological Engineering 37 (6), 4649–4673 (2019).
4. Pandey, B.K., Rajesh, S., Chandra, S.: Numerical evaluation of geogrid-encased stone columns in soft soil under embankment loading. Geotechnical Special Publications 315, 543–551 (2020).
5. Pandey, B.K., Rajesh, S., Chandra, S.: Performance enhancement of encased stone column with conductive natural geotextile under k0 stress condition. Geotextiles and Geomembranes 49(5), 1095-1106 (2021).
6. Virkutytea, J., Sillanpaa, M., Latostenmaa, P.: Electrokinetic soil remediation-critical overview. Science of the Total Environment 289, 97-12 (2002).
7. Acar, Y.B., Hamed, J.T., Alshawabkeh, A.N., Gale, R.J.: Removal of cadmium (II) from saturated kaolinite application of electrical current. Geotechnique 44(2), 355–359 (1994).
8. Silvaa, F.L, Lanzaa, M.R.V., Saezb, C., Rodrigo, M.A.: Electrochemical dewatering for the removal of hazardous species from sludge. Journal of Environmental Management 233, 768–773 (2019).
9. Amipara, B., Galgale, A.D., Shah, N.G.: Enhanced electrokinetic remediation of Zinc contaminated soil by changeover of composite electrolyte. Asian Journal of Water, Environment and Pollution 18(2), 59 – 65 (2021).
10. Han, J.: Principles and practice of ground improvement. Wiley, Hoboken (2015).
11. Hausmann, M.R.: Engineering principles of ground modification. McGraw-Hill, New York (1990).
12. Fourie, A.B., Johns, D.G., Jones, C.J.F.P.: Dewatering of mine tailings using electrokinetic geosynthetics. Canadian Geotechnical Journal 172(44), 160–172 (2007).
13. Fourie, A.B., Jones, C.J.F.P.: Improved estimates of power consumption during dewatering of mine tailings using electrokinetic geosynthetics (EKGs). Geotextiles and Geomembranes 28, 181–190 (2010).
14. Jayasekera, S.: Electrokinetics to modify strength characteristics of soft clayey soils: a laboratory-based investigation. Electrochimica Acta 181, 39–47 (2015).
15. Casagrande, L.: Electro-osmosis in soils. Geotechnique 1(3), 159–177 (1949).
16. Shang, J.Q.: Electrokinetics: engineering applications and recent development. Geotechnical Special Publications 217, 1–8 (2012).
17. Malekzadeh, M., Lovisa, J., Sivakugan, N.: An overview of electrokinetic consolidation of soils. Geotechnical and Geological Engineering 34(3), 759–776 (2016)

18. Gill, R.T., Harbottle, M.J., Smith, J.W.N., Thornton, S.F.: Electrokinetic-enhanced bioremediation of organic contaminants: a review of processes and environmental applications. Chemosphere 107, 31–42 (2014).
19. Khudzari, J.M., Kurian, J., Tartakovsky, B., Raghavan, G.S.V.: Bibliometric analysis of global research trends on microbial fuel cells using Scopus database. Biochemical Engineering Journal 136, 51–60 (2018).
20. Pan, X., Lv, J., Dyck, M., He, H.: Bibliometric Analysis of Soil Nutrient Research between 1992 and 2020. Agriculture 11, 223, 1-12 (2021)
21. Eck, N.J.V., Waltman, L.: Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics, 84, 523–538 (2010).
22. Belluigi, A.: Elettrogeoplasmosi e sua regolazione. Geofisica Pura e Applicata 45 (1), 65 – 96 (1960).