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Reveiw Article

Biodegradation of Marine Pollutants by Microorganisms: A Bibliometric Analysis

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ABSTRACT

The oceans, as a large area of the planet, are of great importance to the biological status of organisms. They are contaminated with different compounds that are dangerous to health conditions. Biodegradation is one way to reduce pollution. Therefore the current review aimed to this bibliometric analysis. Data were collected from published articles in Scopus and Clarivate Analytics Web of Science databases between 1985 and April 2021, and then Scopus documents were examined using VOS viewer and Bibliometrix-package due to their larger number. Analysis was performed for the number of publications per year, document types, sources, keywords, authors, organizations, and countries. The results showed a growing trend in publishing documents from 2010 to 2022. The two keywords biodegradation and bioremediation grew more.

1. Introduction

Over the past few years, the oceans have been used to dispose of waste and litter. Accumulation and stability of these substances in water cause pollution in the ecosystem. Types of marine pollution include crude oil[1], plastic[2], and other chemical pollution[3].

Annually, large volumes of crude oil and its products are transported through waterways, which can lead to ocean pollution. Oil pollution can reduce biodiversity, that various aspects of this issue can be traumatic[4]. Despite the widespread use of plastics in human life, their disposal in the oceans causes many problems that are harmful to health[2]. Environmental microbial flora can degrade plastic compounds. Some researcher work on cynobacteria that ability to biodegradation of crude oil and thus research on cyanobacteria has been promising[5].

Bioremediation is a process in which microorganisms are used to eliminate or reduce environmental pollution. Diverse bioremediation procedures based on microbial metabolisms, such as natural attention, bioaugmentation and biostimulation was designed and created[6]. The biodegradation quality is affected by different factors, including bacterial physiology[7], type of pollutant[8] and environmental conditions[9].

So far, bacteria with the ability to bioremediate have been isolated and identified from different sources such as soft corals, sponges, marine sediments. Ansari et al. introducded the bacterial isolates that had the greatest ability to decompose crude oil from the genera *Cobetia*, *Shewanella*, *Alcanivorax*, and *Cellulosimicrobium* by studying bacteria with the bioremediation ability of Persian Gulf corals in Iran[10]. Ados Santos et al. also performed a mixture of coral prebiotic bacteria intending to degrade the water-soluble part of the oil[11]. The results were not only encouraging for degradation but even promising for improving coral health. Ferrante et al. reported the high capacity of bioaccumulation of Cu in *Chondrilla nucula* sponge, which can be used as bioremediation in polluted coastal areas[12]. In another study, the biodegradability of *Spheciospongia vesparium* sea sponge for dissolved organic matter was investigated[13]. In a study on marine sedimentary origin, resistant strains, such as *Vibrio*, *Pseudoalteromonas*, and *Agarivorans* were identified in contaminated areas. Their results explained that bacterial isolates with ability to tolerate or resistant to polycyclic aromatic hydrocarbon and heavy metals contaminants were present in marine

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sediments that can be a hopeful source for bioaugmentation processes[8].

Accordingly, there are reports of the ability of bacteria to biodegrade in marine environments[14-16]. The purpose of this study was to perform a bibliometric analysis on this subject. Also, review of new finding in this scope of research is another aim of this study.

2. Materials and Methods

Data collection was performed on two comprehensive databases of Clarivate Analytics Web of Science (WoS) and Scopus on April 3, 2021. The date of the last update for the WoS website is April 2, 2021. A total of 952 documents published from 1953 to 2021 were retrieved from Scopus database. and to identify with the WoS database, data were collected from both databases during the period 1985 to 2021 (120 article). The search terms used and other analytics factors in each of the databases are arranged in Table 1.

Because the number of documents published in Scopus was slightly higher than in WoS, further studies were conducted on documents in the Scopus database. In this bibliometric analysis, keywords, authors, journals, and countries were examined using VOS viewer v.1.6.16[17] and Bibliometrix-package[18] in Rstudio software, and the results were recorded.

Contaminants, such as crude oil and other chemical compounds, are present in marine ecosystems. In this analysis, the type of pollution was not the target, and non-separation of the pollution type is one of the limitations of this study.

Table 1. Search terms used and specification documents (1985-2021)

	WoS	Scopus
Search terms	TITLE: “Bioaccumulation” OR “Bioaugmentation” OR “Bioavailability” OR “Biodegradation” OR “Bioremediation” OR “Biosorption” OR “Biostimulation” OR “Biosurfactant” OR “Biotransformation” OR “Degradation” OR “Detoxification” AND TOPIC: “marine” OR “sea” OR “ocean” AND TITLE: “microb*” OR “bacter*”	TITLE: “Bioaccumulation” OR “Bioaugmentation” OR “Bioavailability” OR “Biodegradation” OR “Bioremediation” OR “Biosorption” OR “Biostimulation” OR “Biosurfactant” OR “Biotransformation” OR “Degradation” OR “Detoxification” AND TITLE-ABS-KEY “marine” OR “sea” OR “ocean” AND TITLE “microb*” OR “bacter*”
Results (Total)	861	888
Open-Access	294	298
OA (%)	34/14	33/55
Average Citations Per Item	27/54	-
Average years from publication	-	10/3
Average citations per documents	-	26/02
Average citations per year per doc	-	2/479

3. Result and Discussion

In the continuation of this study, the results are mentioned and discussed.

3.1. Analysis of publication years

As shown in Figure 1, in general, the subject under analysis had a growing trend over the years in both databases. However, in some years, the number of documents has decreased, compared to last year. It may be researcher shift to new scopes. Reducing the number of documents in 2021 because that information is collected in April 2021 and probably until the end of 2021 this amount will increase.

It should be noted that 10 million gallons of oil were discharged into the sea in Alaska when Exxon Valdez ran aground on March 24, 1989[19]. This event and the subsequent damage to marine ecosystems may have contributed to the growth of the subject matter in the coming years.

In Figure 2, the average article citations per year is

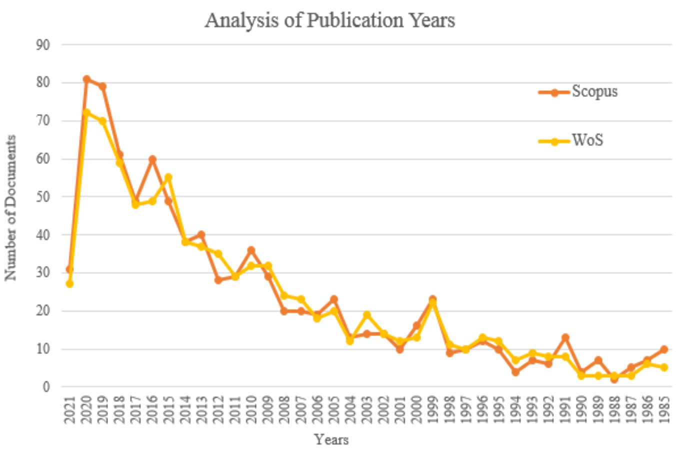

Figure 1. Analysis of publication years

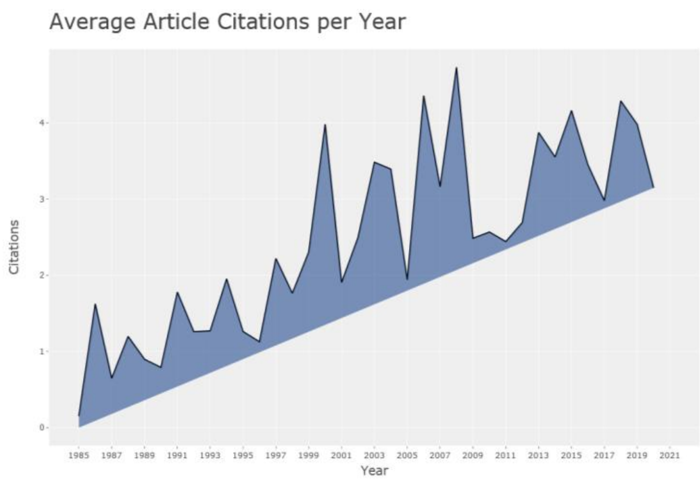

Figure 2. Average article citations per year (Scopus)

Table 2. Most global cited documents

Paper	Source	TC	TC per year	Reference
Bioremediation of high molecular weight polycyclic aromatic hydrocarbons: a review of the microbial degradation of benzo[a]pyrene	International Biodeterioration & Biodegradation	802	36	46
Plastics: Environmental and Biotechnological Perspectives on Microbial Degradation	Applied and Environmental Microbiology	66	22	47
Microbial Ecotoxicology of Marine Plastic Debris: A Review on Colonization and Biodegradation by the "Plastisphere"	Frontiers in Microbiology	64	21	48
Degradation of plastics and plastic-degrading bacteria in cold marine habitats	Applied Microbiology and Biotechnology	75	18	49
Recent studies in microbial degradation of petroleum hydrocarbons in hypersaline environments	Frontiers in Microbiology 2014	146	18	50
Marine methane paradox explained by bacterial degradation of dissolved organic matter	Nature Geoscience	104	17	51
Marine Microbial Assemblages on Microplastics: Diversity, Adaptation, and Role in Degradation	Annual Review of Marine Science	34	17	52
Whole genome analysis of the marine Bacteroidetes*'Gramella forsetii'* reveals adaptations to degradation of polymeric organic matter	Environmental Microbiology	249	15	53
Biodegradation of low-density polyethylene by marine bacteria from pelagic waters, Arabian Sea, India	Marine Pollution Bulletin	126	14	54
Occurrence of endocrine disrupting compounds in aqueous environment and their bacterial degradation: A review	Critical Reviews in Environmental Science and Technology	84	14	55

TC: Total citation

plotted. As it turns out, this is an uptrend and it has increased over the years. The highest value of this metric in 2008 was 4/7. Table 2 lists 10 documents with the highest number of total citations (TC) per year.

3.2. Analysis of keywords

The abundance of keywords Plus and the author's keywords in the documents collected by the Scopus database were determined to be 6192 and 1927, respectively. The results related to the analysis of index keywords in VOS viewer software are shown in Figure 3. The analysis was performed for the minimum number of occurrences 20 of a keyword, which was classified into 4 clusters. The characteristics of each cluster in Figure 3 are recorded in Table 3. According to the purpose of this study of bibliometric analysis, two clusters included 1 and 2 with the titles of Biodegradation and Bacteria (Microorganisms) had the most items. However, the highest total link strength was determined for the five Index Keywords Article, Nonhuman, Bioremediation, Biodegradation, and Bacteria as 7173, 6492, 6224, 5997, and 5698, respectively.

Figure 4 presents the growth rate of 10 words over the years. According to this chart, although the word Biodegradation was more important than the word Bioremediation in 1989-2008, both of these words grew to the same extent in 2008-2014. Furthermore, the highest growth rate of the word Bacteria (Microorganism) is observed in 2015, after which it has slowly decreased. However, words with almost the same meaning even by a mention, such as Bacterium and Bacteria are still growing.

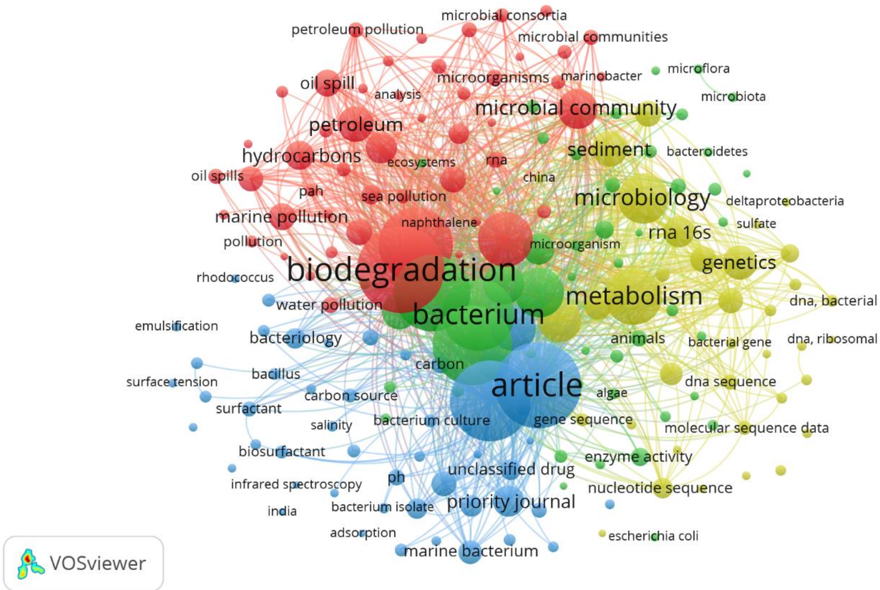

Figure 3. Index keywords analysis

Table 3. Index keyword clustering using VOS viewer

Red	Cluster 1 (51 items)	Biodegradation
Green	Cluster 2 (51 items)	Bacteria (Microorganisms)
Blue	Cluster 3 (50 items)	Article
Yellow	Cluster 4 (37 items)	Metabolism

3.3. Analysis of Document types

The types of documents published in both databases are shown graphically in Figure 5. Although the classification of document types in both databases was slightly different, most were related to articles. Regarding the Scopus database, the second rank of most documents belonged to the conference paper category. Also, review documents formed a smaller percentage compared to other types of article. Generally, this chart (Figure 5) can show the growing trend of the subject matter.

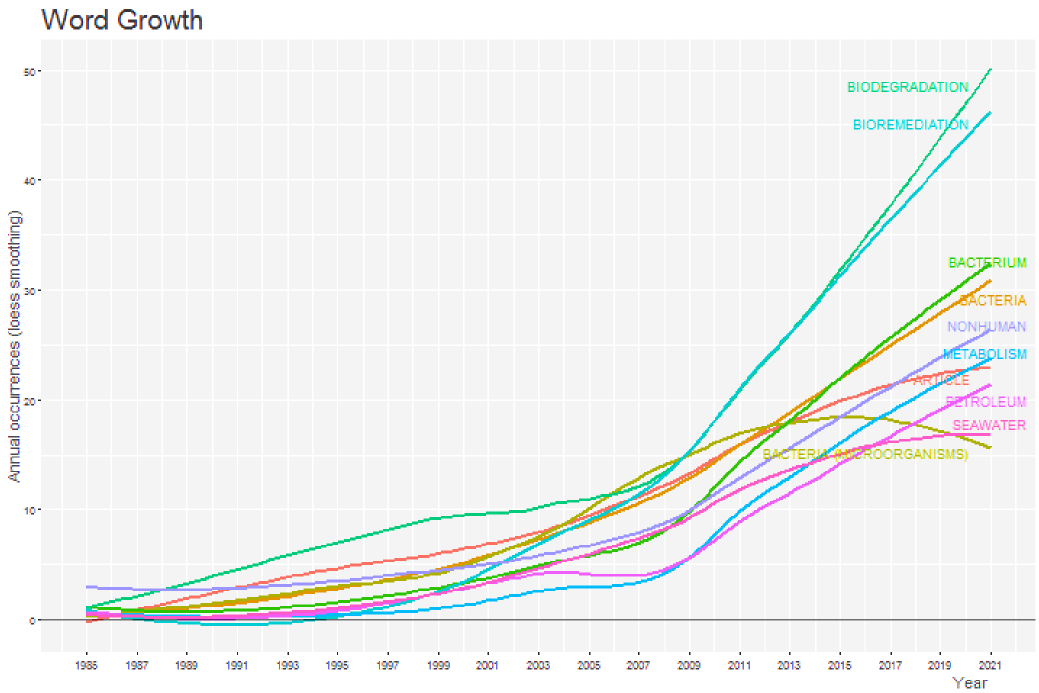

Figure 4. Word growth (Scopus)

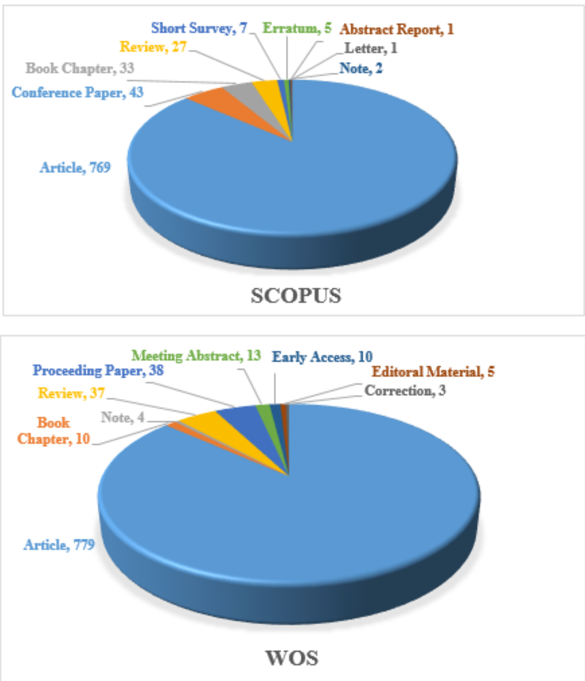

Figure 5. Types of documents in Scopus and WoS data databases

3.4. Analysis of Sources

Figure 6 shows the growth rate of 6 sources in this research topic by year. Figure 7 shows the core sources according to Bradford's law. This rule is used in bibliometric analyzes to identify major or core journals in that field of research[20-22].

However, the results of these figures, show the two sources of Marine Pollution Bulletin [23-25] and Frontiers in Microbiology[8,26-29]. The new Research, have grown significantly in recent years. The CiteScore for these two sources was 6/7 and 6/4 in 2019, respectively.

3.5. Analysis of authors

The results of the authors' general analysis based on the documents collected from Scopus are presented in Table 4. In Figure 8, each line shows the author's timeline and the size of the circle, the number of documents the author has published, which is between 1 and 5. For example, 5 documents in 2018 have been published by Brakstad OG. Furthermore, the color intensity was comparable to the total citations per year of the published records. This value varies from 0 to 27. The highest amount in 2015 for the author Cappello S was recorded at 27/286. Likewise, in Table 5 are the top ten authors listed based on the most TC per year.

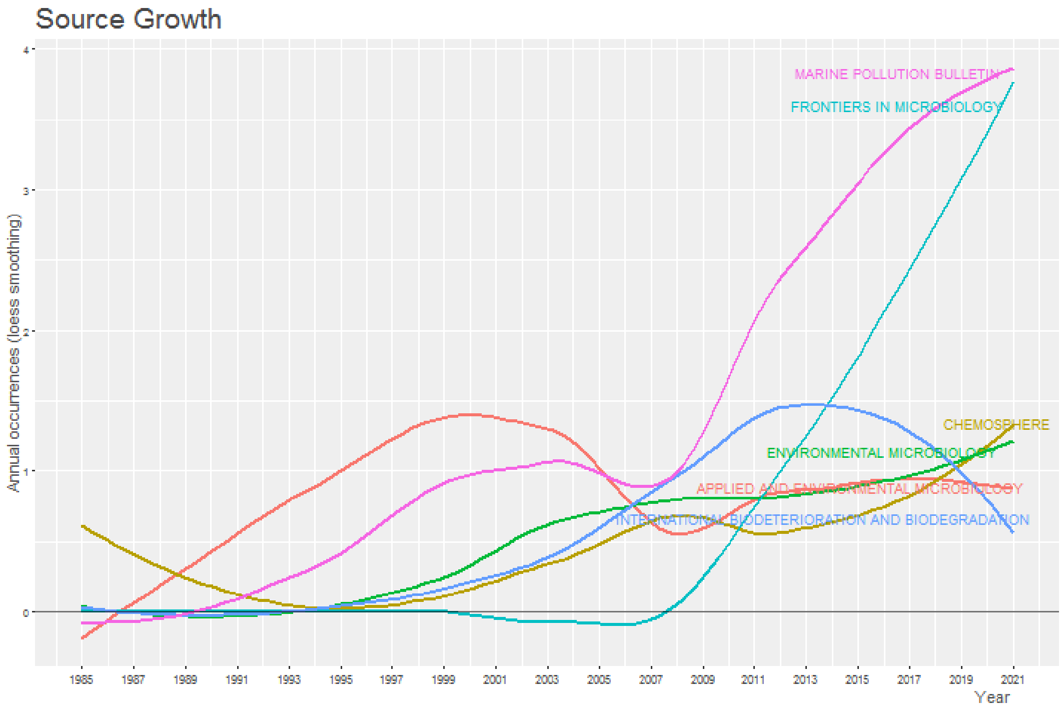

Figure 6. Growth of sources of documents collected from the Scopus database

3.6. Analysis of organizations

Organizational analysis using VOS viewer was performed based on at least three documents from each organization, each of which was listed at least three times. Of 2113 organizations, 11 were identified. Information about these 11 organizations is listed in Table 6. Additionally, the time classification of these organizations about the subject under study is shown in Figure 8.

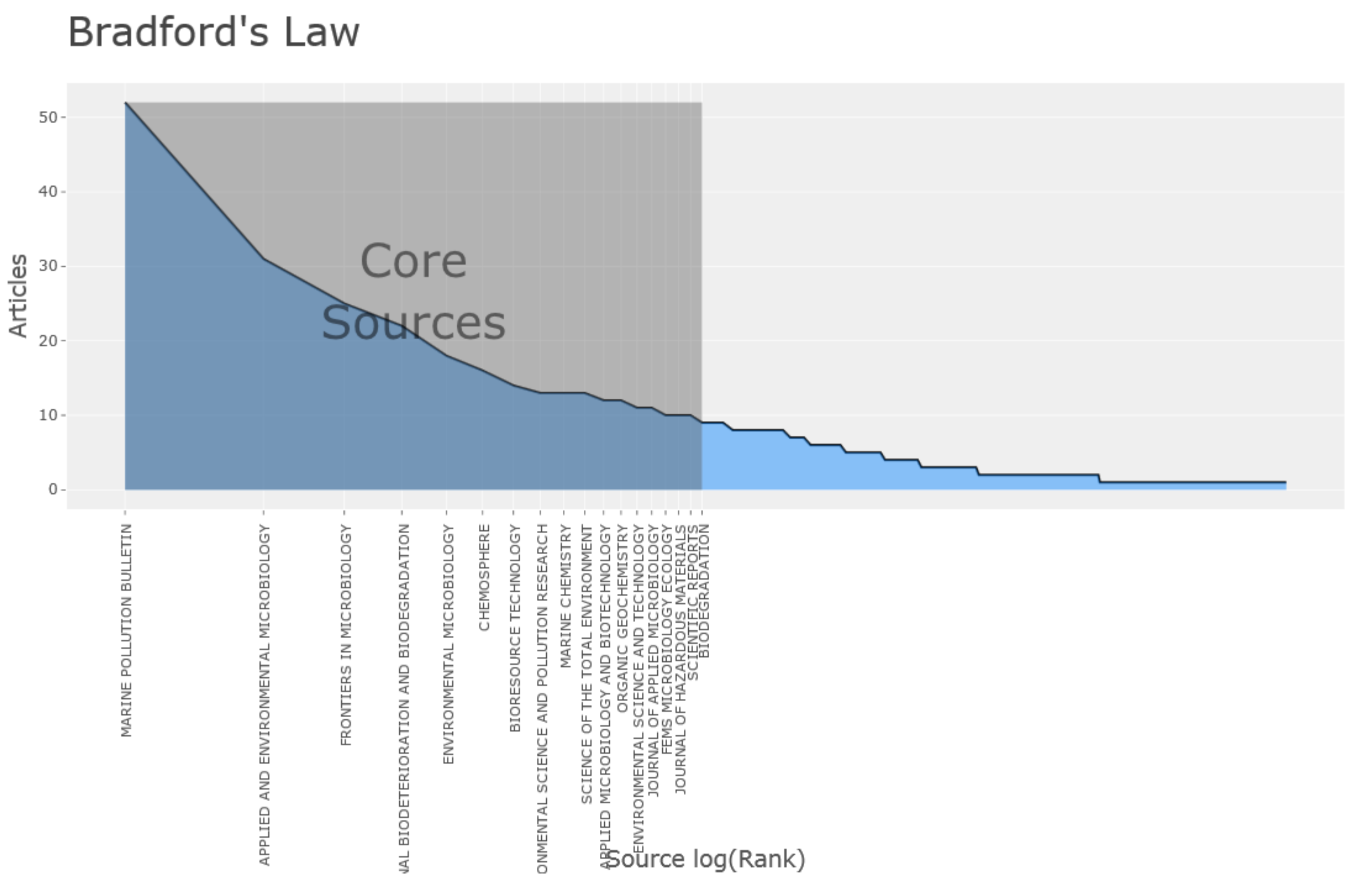

Figure 7. Core Sources

Table 4. Analysis of authors and their relationships from Scopus documents.

Authors		Authors' collaboration	
Description	**Results**	**Description**	**Result**
Authors	3319	Single-authored documents	35
Authors Appearances	4352	Documents per author	0/268
Authors of single-authored documents	34	Author per document	3/74
Authors of multi-authored documents	3285	Co-Authors per documents	4/9
		Collaboration index	3/85

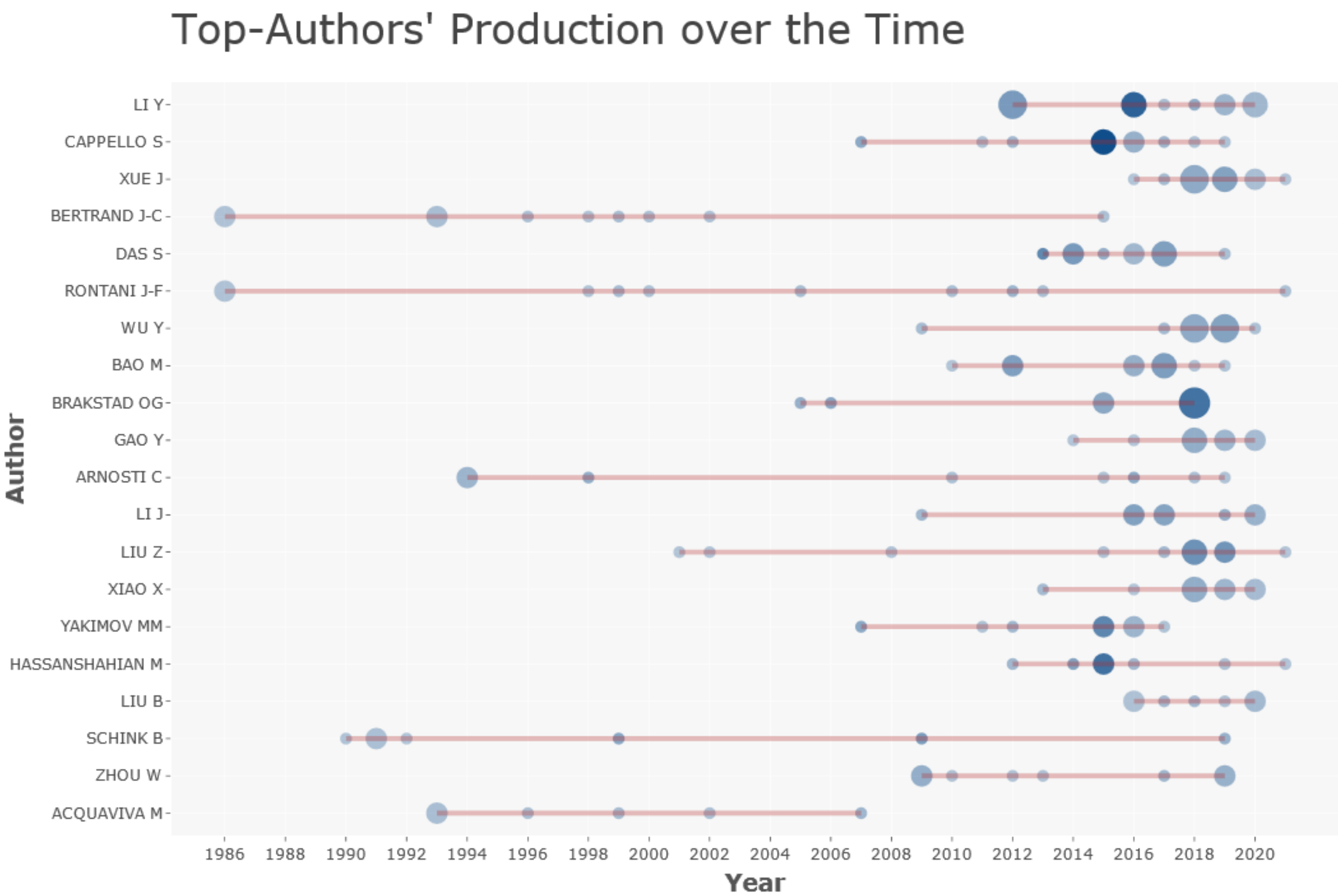

Figure 8. Top-authors' publication over the time

3.7. Analysis of countries

The results of this part of the analysis showed that 73 countries have published documents related to this issue in Scopus. First to third place were for the United States, China, and India with the number of documents 158, 137 and 105, respectively. Figure 10 shows countries with at least 10 documents published and their number is displayed. Moreover, 16 countries have published only one document and 11 documents have been classified as undefined.

Figure 11 presents the cooperation between countries on the world map. The highest level of collaboration was recorded for the USA and Germany (n= 12 cases). In this image, each red line represents a collaboration between countries, and the dark blue regions have published

Table 5. Top ten authors' publication per year

	Author	Year	TC	TC per Year
1	Cappello S	2015	191	27/286
2	Li Y	2016	135	22/500
3	Hassanshahian M	2015	133	19/000
4	Brakstad OG	2018	75	18/750
5	Yakimov MM	2015	99	14/143
6	Das S	2013	123	13/667
7	Liu Z	2018	47	11/750
8	Liu Z	2019	33	11/000
9	Das S	2014	79	9/875
0	Li Y	2012	95	9/500

Table 6. Organizations with at least 3 documents and 3 citations

Organization	Documents	Citations	Total link strength
Department of Marine Sciences, University of Georgia, Athens, GA, United States	3	31	2
Department of Microbiology, University of Georgia, Athens, GA, United States	3	62	2
Center for Geomicrobiology, Department of Bioscience, Aarhus University, Aarhus, Denmark	3	26	0
College of Chemical and Environmental Engineering, Shandong University of Science and Technology, Qingdao, Shandong, 266590, China	4	19	0
College of Marine Studies, University of Delaware, Lewes, DE 19958, United States	4	243	0
Department of Biology, Faculty of Sciences, Shahid Bahonar University of Kerman, Kerman, Iran	3	47	0
Department of Biotechnology, Indian Institute of Technology, Kharagpur, West Bengal 721302, India	3	242	0
Key Laboratory of Marine Chemistry Theory and Technology, Ministry of Education, Ocean University of China, Qingdao, 266100, China	3	20	0
Key Laboratory of Marine Chemistry Theory and Technology, Ministry of Education, Ocean University of China, Qingdao, China	3	39	0
Laboratory of Environmental Microbiology and Ecology (LEnME), Department of Life Science, National Institute of Technology, Rourkela, Odisha 769 008, India	4	56	0
School of Environmental Science and Engineering, Shandong University, Jinan, Shandong 250100, China	3	29	0

more documents.

3.8. Trends of topics

The trend of topics by year is shown in Figure 12. Keywords plus are selected based on a minimum frequency of 20. Accordingly, with 601 frequencies in 2015, the keyword Biodegradation was the highest, and then with a frequency of 492 in 2016, the keyword Bioremediation was determined. Moreover, keywords, such as Gene sequence[30], Gasoline[31], Microflora[32], Wastewater treatment[33-35], and Microbiota[36] in 2019 were identified with frequencies of 36, 32, 27, 26, and 25, respectively.

3.9. Tree-fields Plot

The relationship between author's keywords and sources is shown in Figure 13. Larger squares in each row represent the largest value relative to their peers. For example, Cappello (author) mentioned more bioremediation keyword in his documents[37-43], while others used the marine environment keyword more in their documents[10,39,41,42,44,45-55].

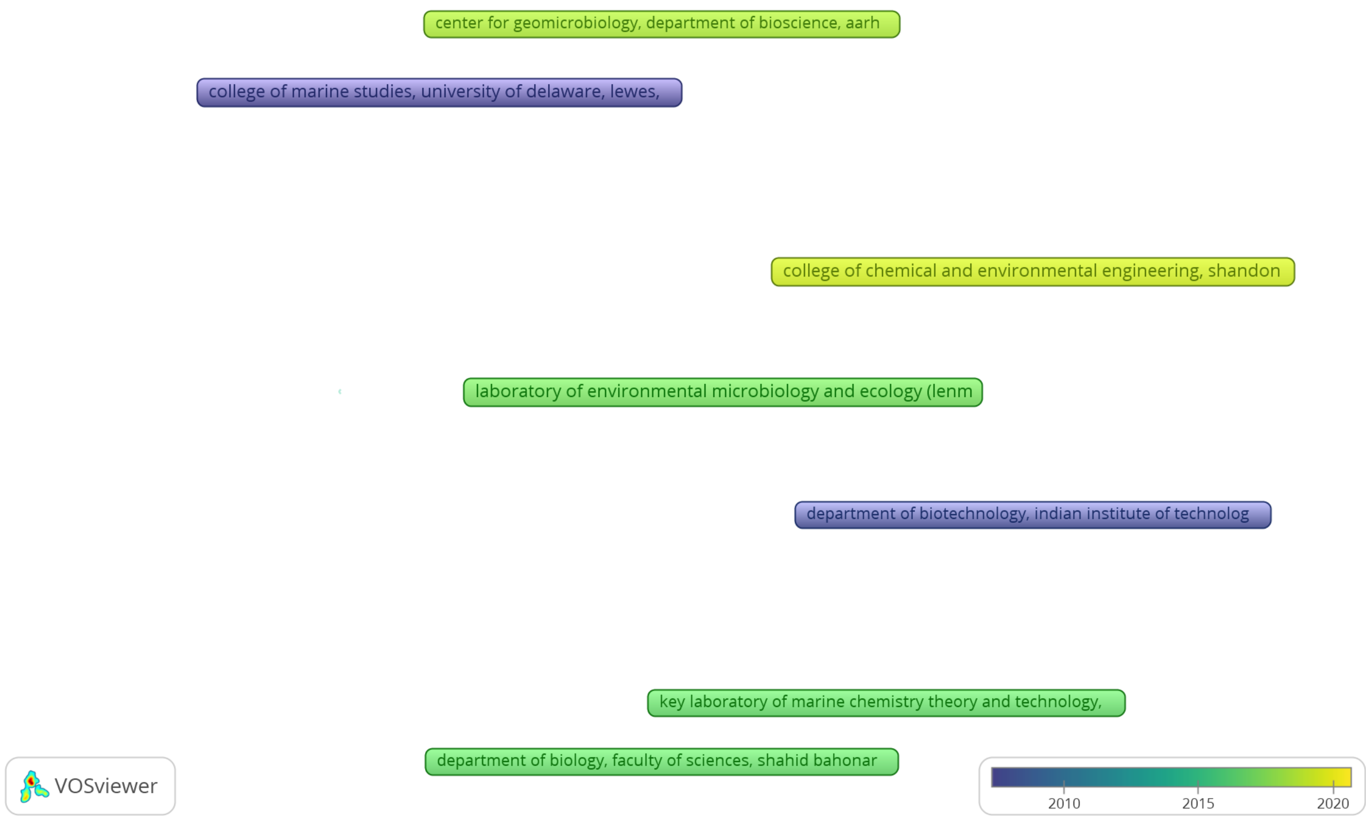

Figure 9. Categorize organizations by year

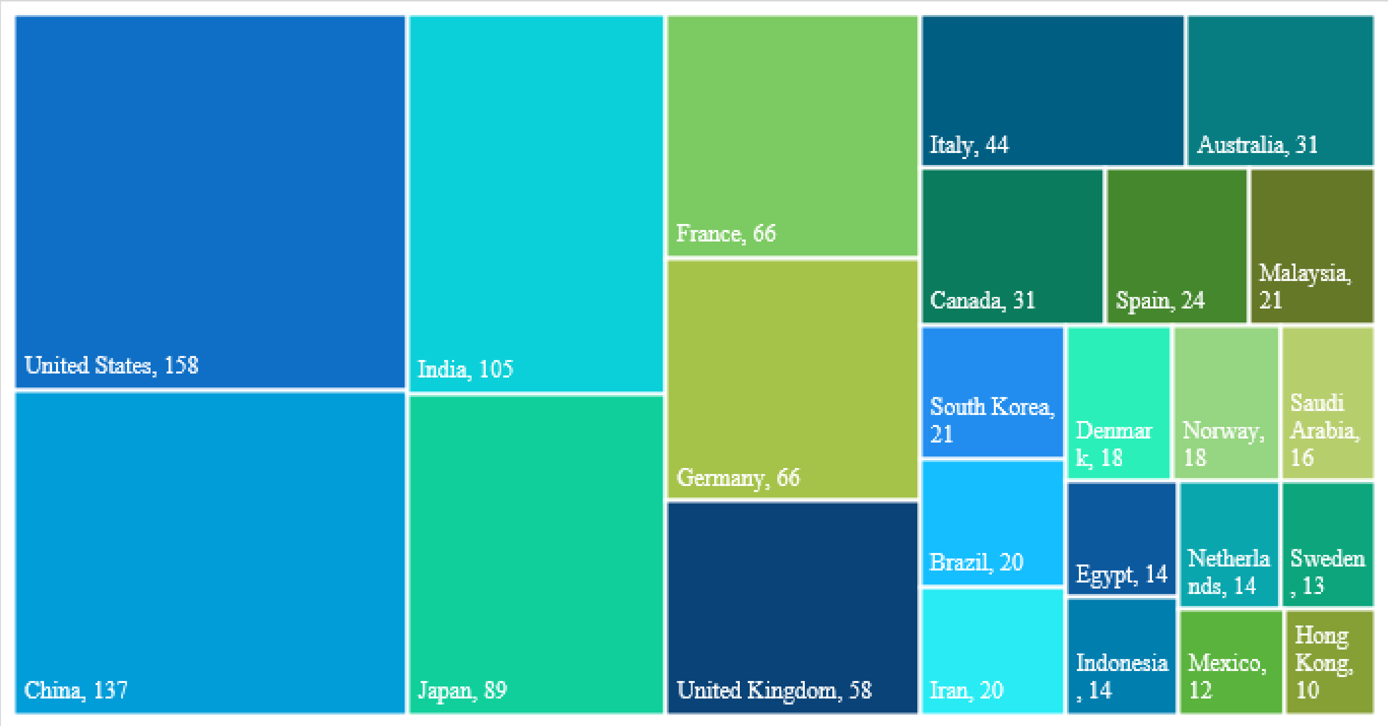

Figure 10. Chart of countries with at least 10 documents published in Scopus

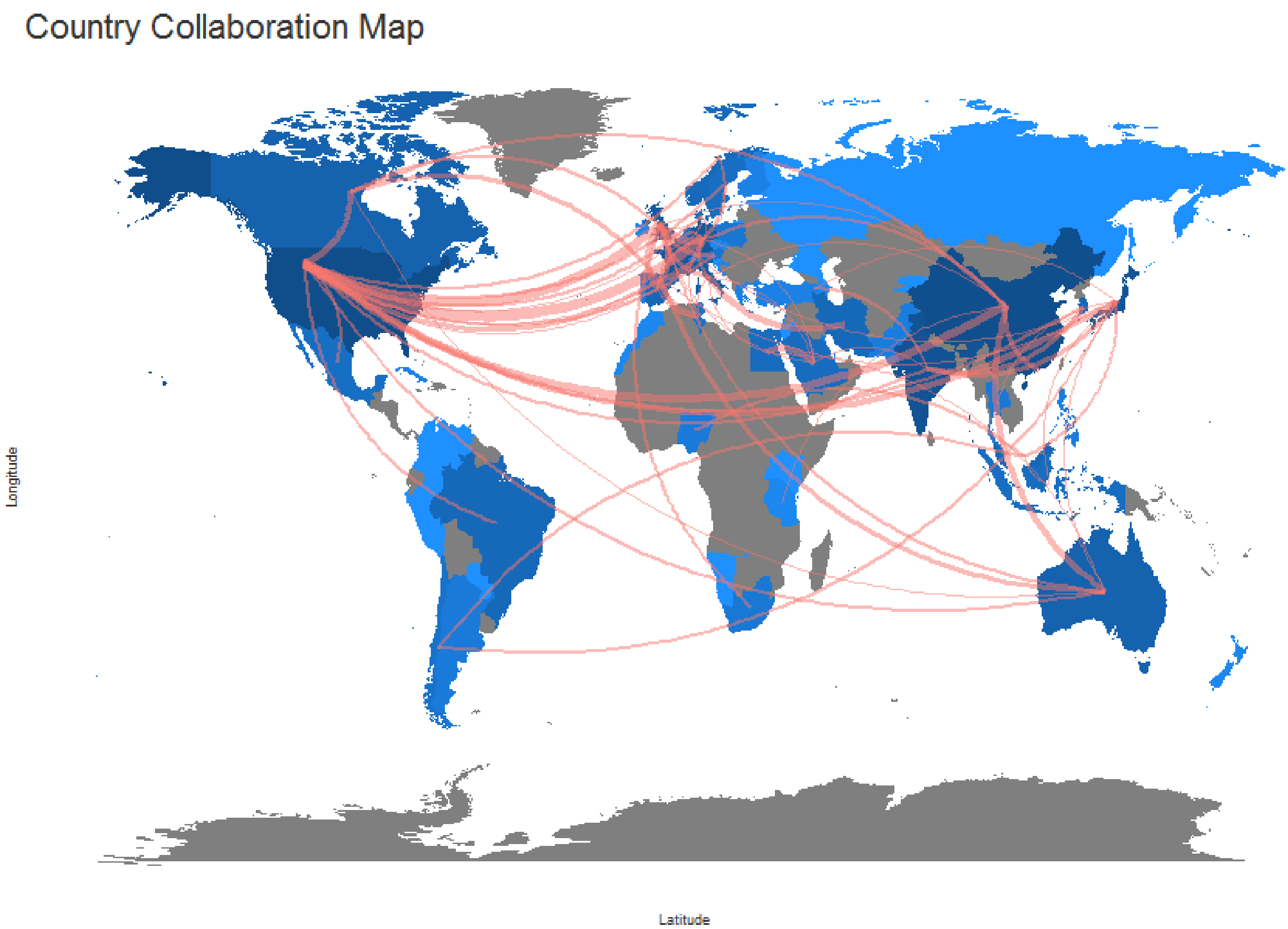

Figure 11. Country collaboration map

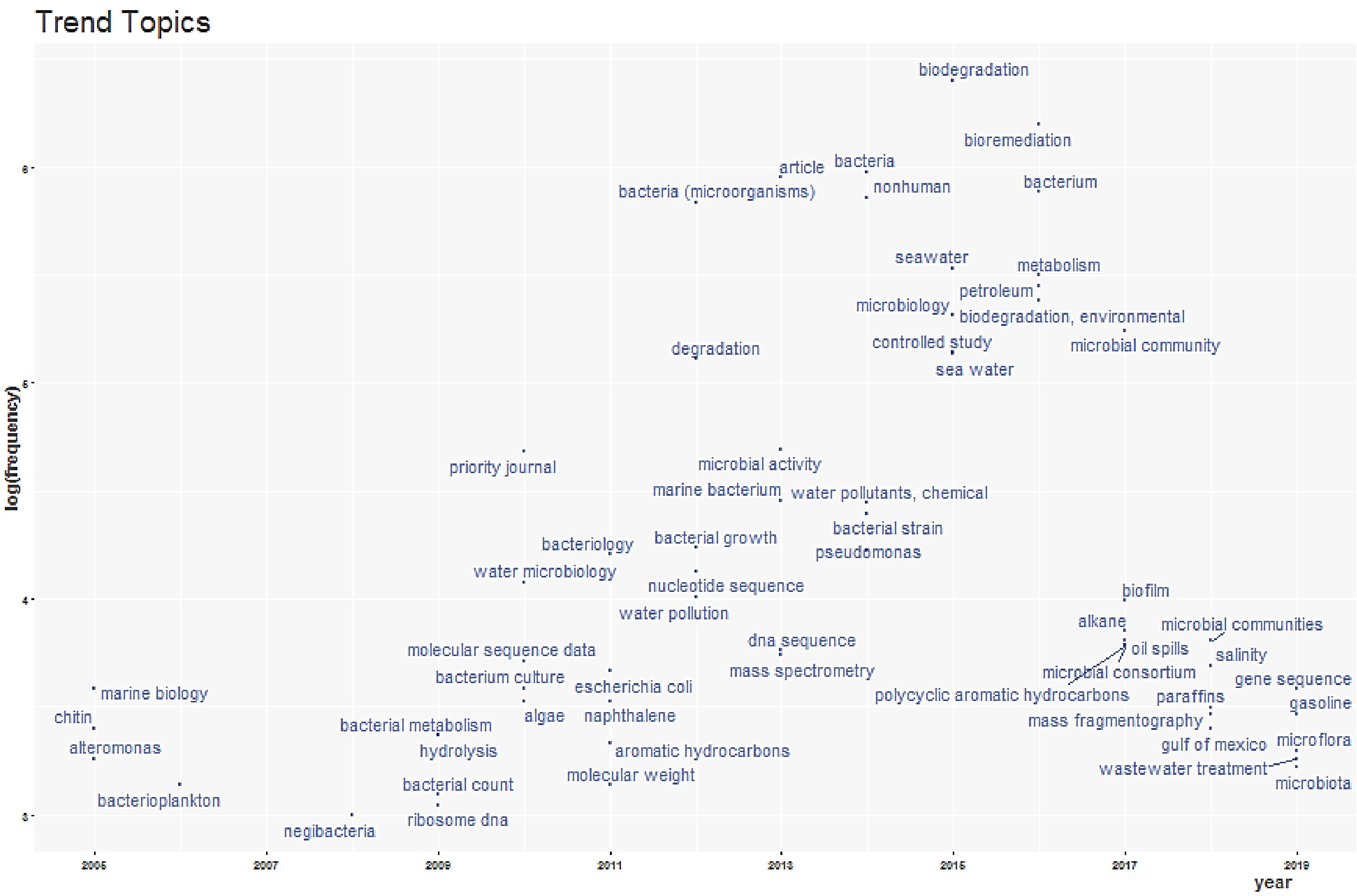

Figure 12. Trends of topics

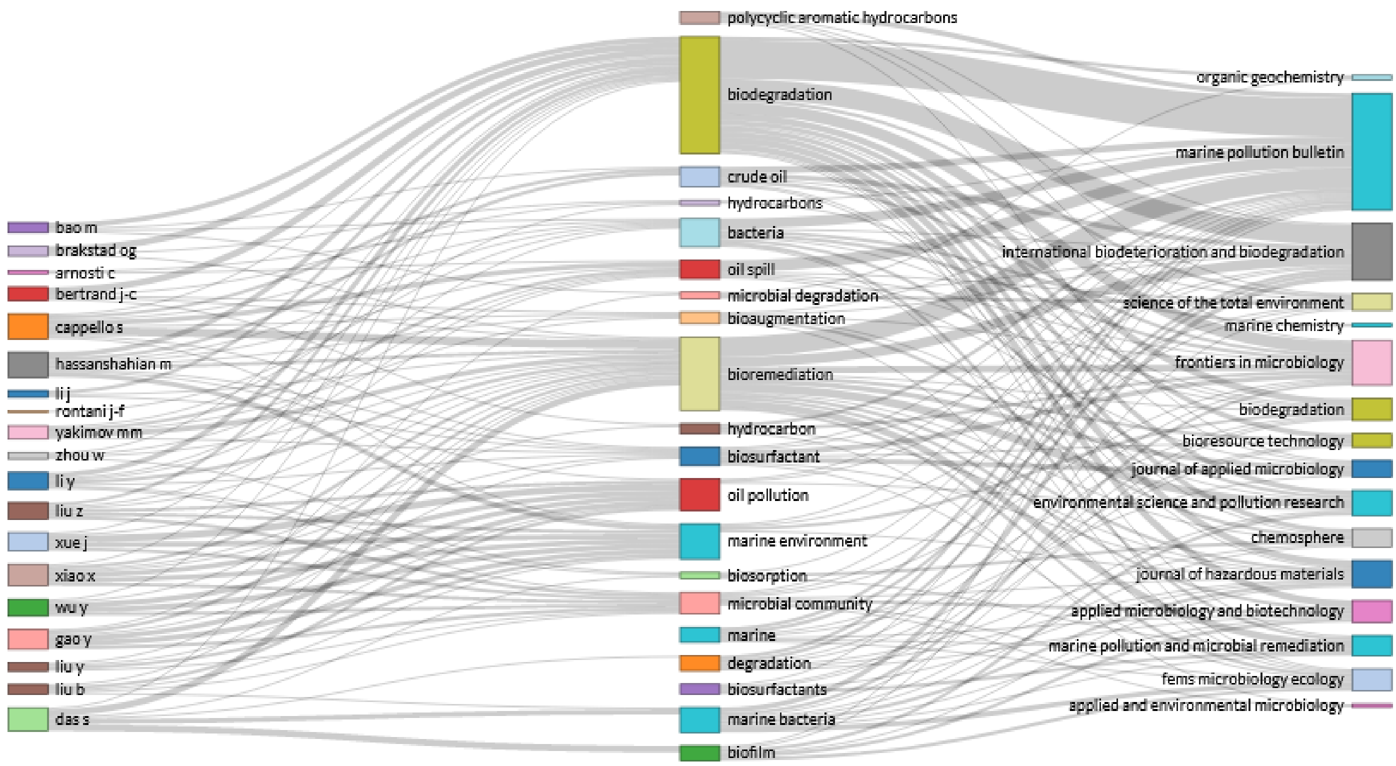

Figure 13. Tree-fields Plot. Author name (left), keyword (middle) and source (right)

4. Conclusion

The elimination of contamination from marine environments by bacteria has been interested for researchers at past 35 years and it is likely to continue in the coming years. According to the results of this study, at least 24 countries are researching this issue, but the relationship and cooperation between research organizations are low. Therefore, increasing cooperation between countries and organizations in the future is recommended. Regarding the results of the trend in 2019, it is likely that future research will focus on the use of microflora in water treatment.

Declarations

Competing interests

No potential competing interest was reported by the authors.

Authors' contribution

All authors were involved in interpretation and data collection, design of the article, review, and manuscript preparation.

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Ethical considerations

The authors checked for plagiarism and consented to the publishing of the article. The authors have also checked the article for data fabrication, double publication, and redundancy.

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References

1. Li XF, Zhao L, and Adam M. Biodegradation of marine crude oil pollution using a salt-tolerant bacterial consortium isolated from Bohai Bay, China. Mar Pollut Bull. 2016; 105(1): 43-50. DOI: 10.1016/j.marpolbul.2016.02.073
2. Oliveira J, Belchior A, da Silva VD, Rotter A, Petrovski Z, Almeida PL, et al. Marine environmental plastic pollution: Mitigation by microorganism degradation and recycling valorization. Front Mar Sci. 2020; 7: 517126. Available at: https://www.frontiersin.org/articles/10.3389/fmars.2020.567126/full
3. Marchand M. Marine chemical pollution. What policies for a lasting protection of the ocean and coastal seas?. L'Act Chim. 2008; 325: 35-40.
4. Hassanshahian M, Amirinejad N, and Behzadi MA. Crude oil pollution and biodegradation at the Persian Gulf: A comprehensive and review study. J Environ Health Sci Eng. 2020; 18(2): 1415-1435. DOI: 10.1007/s40201-020-00557-x
5. Barone GD, Ferizovic D, Biundo A, and Lindblad P. Hints at the applicability of microalgae and cyanobacteria for the biodegradation of plastics. Sustainability, 2020; 12(24): 10449. DOI: 10.3390/su122410449
6. Hidalgo KJ, Sierra-Garcia IN, Dellagnezze BM, and de Oliveira VM. Metagenomic insights into the mechanisms for biodegradation of polycyclic aromatic hydrocarbons in the oil supply chain. Front Microbiol, 2020; 11: 561506. DOI: 10.3389/fmicb.2020.561506
7. Cao Y, Zhang B, Zhu Z, Song X, Cai Q, Chen B, et al. Microbial eco-physiological strategies for salinity-mediated crude oil biodegradation. Sci Total Environ. 2020; 727: 138723. DOI: 10.1016/j.scitotenv.2020.138723
8. Dell'Anno F, Rastelli E, Tangherlini M, Corinaldesi C, Sansone C, Brunet C, et al. Highly contaminated marine sediments can host rare bacterial taxa potentially useful for bioremediation. Front Microbiol. 2021; 12: 584850. DOI: 10.3389/fmicb.2021.584850
9. Tong T, Li R, Chen J, Ke Y, and Xie S. Bisphenol A biodegradation differs between mudflat and mangrove forest sediments. Chemosphere, 2021; 270: 128664. DOI: 10.1016/j.chemosphere.2020.128664
10. Ansari N, Rokhbakhsh-Zamin F, Hassanshahian M, and Hesni MA. Biodegradation of crude oil using symbiont crude-oil degrading bacteria isolated from corals collected at the Persian Gulf. J Chem Technol Biotechnol. 2021; 96(7): 1882-1892. DOI: 10.1002/jctb.6707
11. Ados Santos HF, Duarte GAS, da Costa Rachid CT, Chaloub RM, Calderon EN, de Barros Marangoni LF, et al. Impact of oil spills on coral reefs can be reduced by bioremediation using probiotic microbiota. Sci Rep. 2015; 5: 18268. DOI: 10.1038/srep18268
12. Ferrante M, Vassallo M, Mazzola A, Brundo MV, Pecoraro R, Grasso A, et al. *In vivo* exposure of the marine sponge Chondrilla nucula Schmidt, 1862 to cadmium (Cd), copper (Cu) and lead (Pb) and its potential use for bioremediation purposes. Chemosphere, 2018; 193: 1049-1057. DOI: 10.1016/j.chemosphere.2017.11.144
13. Letourneau ML, Hopkinson BM, Fitt WK, and Medeiros PM. Molecular composition and biodegradation of loggerhead sponge Spheciospongia vesparium exhalent dissolved organic matter. Mar Environ Res. 2020; 162: 105130. DOI: 10.1016/j.marenvres.2020.105130
14. Ameen FA, Hamdan AM, and El-Naggar MY. Assessment of the heavy metal bioremediation efficiency of the novel marine lactic acid bacterium, Lactobacillus plantarum MF042018. Sci Rep. 2020; 10: 314. DOI: 10.1038/s41598-019-57210-3
15. Amer RA, Mapelli F, El Gendi HM, Barbato M, Goda DA, Corsini A, et al. Bacterial diversity and bioremediation potential of the highly contaminated marine sediments at El-Max District (Egypt, Mediterranean Sea). Biomed Res Int. 2015; 2015: 981829. DOI: 10.1155/2015/981829
16. Xu M, Fu X, Gao Y, Duan L, Xu C, Sun W, et al. Characterization of a biosurfactant-producing bacteria isolated from Marine environment: Surface activity, chemical characterization and biodegradation. J Environ Chem Eng. 2020; 8(5): 104277. DOI: 10.1016/j.jece.2020.104277
17. Van Eck NJ, and Waltman L. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics. 2010; 84(2): 523-538. DOI: 10.1007/s11192-009-0146-3
18. Aria M, and Cuccurullo C. Bibliometrix: An R-tool for comprehensive science mapping analysis. J Informetr, 2017; 11(4): 959-975. DOI: 10.1016/j.joi.2017.08.007
19. Wolfe D, Michel J, Hameedi M, Payne J, Galt J, Watabayashi G, et al. The fate of the oil spilled from the Exxon Valdez. Environmental Science & Technology, 1994; 28(13): 560A-568A. DOI: 10.1021/es00062a001
20. Bradford SC. Sources of information on specific subjects. Engineering. 1934; 137: 85-86. DOI: 10.1177/016555158501000407
21. Patra SK, Bhattacharya P, and Verma N. Bibliometric study of literature on Bibliometrics. *DESIDOC.* J Inf Technol. 2006; 26(1): 27-32. Available at: http://eprints.rclis.org/23781/
22. Venable GT, Shepherd BA, Roberts ML, Taylor DR, Khan NR, and Klimo P. An application of Bradford's law: Identification of the core journals of pediatric neurosurgery and a regional comparison of citation density. Childs Nerv Syst. 2014; 30(10): 1717-1727. DOI: 10.1007/s00381-014-2481-9
23. Bacosa HP, Kang A, Lu K, and Liu Z. Initial oil concentration affects hydrocarbon biodegradation rates and bacterial community composition in seawater. Mar Pollut Bull. 2021; 162: 111867 DOI: 10.1016/j.marpolbul.2020.111867
24. Cerqueda-García D, García-Maldonado JQ, Aguirre-Macedo L, and García-Cruz U. A succession of marine bacterial communities in batch reactor experiments during the degradation of five different

petroleum types. Mar Pollut Bull. 2020; 150: 110775. DOI: 10.1016/j.marpolbul.2019.110775
25. Zambrano MC, Pawlak JJ, Daystar J, Ankeny M, Goller CC, and Venditti RA. Aerobic biodegradation in freshwater and marine environments of textile microfibers generated in clothes laundering: Effects of cellulose and polyester-based microfibers on the microbiome. Mar Pollut Bull. 2020; 151: 110826 DOI: 10.1016/j.marpolbul.2019.110826
26. Adlan NA, Sabri S, Masomian M, Ali MSM, and Rahman RNZRA. Microbial biodegradation of paraffin wax in malaysian crude oil mediated by degradative enzymes. Front Microbiol. 2020; 11: 565608. DOI: 10.3389/fmicb.2020.565608
27. Jin M, Chen YL, He X, Hou Y, Chan Z, and Zeng R. Amelioration of androgenetic alopecia by algal oligosaccharides prepared by deep-sea bacterium biodegradation. Front Microbiol, 2020; 11: 567060. DOI: 10.3389/fmicb.2020.567060
28. Liu S, Baetge N, Comstock J, Opalk K, Parsons R, Halewood E, et al. Stable isotope probing identifies bacterioplankton lineages capable of utilizing dissolved organic matter across a range of bioavailability. Front Microbiol. 2020; 11: 580397. DOI: 10.3389/fmicb.2020.580397
29. Mohanan N, Montazer Z, Sharma PK, and Levin DB. Microbial and enzymatic degradation of synthetic plastics. Front Microbiol. 2020; 11: 580709. DOI: 10.3389/fmicb.2020.580709
30. Hamdan HZ, Salam DA, and Saikaly PE. Characterization of the microbial community diversity and composition of the coast of Lebanon: Potential for petroleum oil biodegradation. Mar Pollut Bull. 2019; 149: 110508. DOI: 10.1016/j.marpolbul.2019.110508
31. Iwaki H, Yamamoto T, and Hasegawa Y. Isolation of marine xylene-utilizing bacteria and characterization of Halioxenophilus aromaticivorans gen. nov., sp. nov. and its xylene degradation gene cluster. FEMS Microbiol Lett. 2018; 365(7). DOI: 10.1093/femsle/fny042
32. Dashti N, Ali N, Salamah S, Khanafer M, Al-Shamy G, Al-Awadhi H, et al. Culture-independent analysis of hydrocarbonoclastic bacterial communities in environmental samples during oil-bioremediation. MicrobiologyOpen. 2019; 8(2): e00630. DOI: 10.1002/mbo3.630
33. Abubakar M, Habib NMSA, Manogaran M, Yasid NA, Alias SA, Ahmad SA, et al. Response surface-based optimization of the biodegradation of a simulated vegetable oily ballast wastewater under temperate conditions using the antarctic bacterium Rhodococcus erythropolis ADL36. Desalination Water Treat. 2019; 144: 129-137. Available at: https://www.deswater.com/DWT_abstracts/vol_144/144_2019_129.pdf
34. Bailón-Salas AM, Ordaz-Díaz LA, Valle-Cervantes S, López-Miranda J, Urtiz-Estrada N, Páez-Lerma JB, et al. Characterization of culturable bacteria from pulp and paper industry wastewater, with the potential for degradation of cellulose, starch, and lipids. BioResources. 2019; 13(3): 5052-5064. Available at: https://bioresources.cnr.ncsu.edu/wp-content/uploads/2018/05/BioRes_13_3_5052_BailonS_OVLUPR_Charac_Culturable_Bacteria_Pulp_Paper_Industry_Wastewater_13728.pdf
35. Jiang L, Chen X, Qin M, Cheng S, Wang Y, and Zhou W. On-board saline black water treatment by bioaugmentation original marine bacteria with Pseudoalteromonas sp. SCSE709-6 and the associated microbial community. Bioresour Technol. 2019; 273: 496-505. DOI: 10.1016/j.biortech.2018.11.043
36. Jang J, Forbes VE, and Sadowsky MJ. Lack of evidence for the role of gut microbiota in PAH biodegradation by the polychaete Capitella teleta. Sci Total Environ. 2020; 725: 138356. DOI: 10.1016/j.scitotenv.2020.138356
37. Cappello S, Caruso G, Zampino D, Monticelli LS, Maimone G, Denaro R, et al. Microbial community dynamics during assays of harbour oil spill bioremediation: A microscale simulation study. J Appl Microbiol. 2007; 102(1): 184-194. DOI: 10.1111/j.1365-2672.2006.03071.x
38. Cappello S, Crisari A, Denaro R, Crescenzi F, Porcelli F, and Yakimov MM. Biodegradation of a bioemulsificant exopolysaccharide (EPS2003) by marine bacteria. Water, Air, and Soil Pollution. 2011; 214: 645-652. Available at: https://link.springer.com/article/10.1007/s11270-010-0452-7
39. Cappello S, Genovese M, Della Torre C, Crisari A, Hassanshahian M, Santisi S, et al. Effect of bioemulsificant exopolysaccharide (EPS2003) on microbial community dynamics during assays of oil spill bioremediation: A microcosm study. Mar Pollut Bull. 2012; 64(12): 2820-2828. DOI: 10.1016/j.marpolbul.2012.07.046
40. Gentile G, Bonsignore M, Santisi S, Catalfamo M, Giuliano L, Genovese L, et al. Biodegradation potentiality of psychrophilic bacterial strain Oleispira antarctica RB-8T. Mar Pollut Bull. 2016; 105(1): 125-130. DOI: 10.1016/j.marpolbul.2016.02.041
41. Santisi S, Cappello S, Catalfamo M, Mancini G, Hassanshahian M, Genovese L, et al. Biodegradation of crude oil by individual bacterial strains and a mixed bacterial consortium. Braz J Microbiol. 2015; 46(2): 377-387. DOI: 10.1590/s1517-838246120131276
42. Santisi S, Catalfamo M, Bonsignore M, Gentile G, Di Salvo E, Genovese M, et al. Biodegradation ability of two selected microbial autochthonous consortia from a chronically polluted marine coastal area (Priolo Gargallo, Italy). J Appl Microbiol. 2019; 127(3): 618-629. DOI: 10.1111/jam.14246
43. Zoccali M, Cappello S, and Mondello L. Multilevel characterization of marine microbial biodegradation potentiality by means of flow-modulated comprehensive two-dimensional gas chromatography combined with a triple quadrupole mass spectrometer. J Chromatogr A. 2018; 1547: 99-106. DOI: 10.1016/j.chroma.2018.03.013
44. Hassanshahian M. Isolation and characterization of biosurfactant producing bacteria from Persian Gulf (Bushehr provenance). Mar Pollut Bull. 2014; 86(1-2): 361-366. DOI: 10.1016/j.marpolbul.2014.06.043
45. Hassanshahian M, Bayat Z, Cappello S, Smedile F, and Yakimov M. Comparison the effects of bioaugmentation versus biostimulation on marine microbial community by PCR-DGGE: A mesocosm scale. J Environ Sci (China), 2016; 43: 136-146. DOI: 10.1016/j.jes.2015.09.013
46. Juhasz AL, and Naidu R. Bioremediation of high molecular weight polycyclic aromatic hydrocarbons: A review of the microbial degradation of benzo[a]pyrene. Int Biodeterior Biodegradation. 2000; 45(1-2): 57-88. DOI: 10.1016/S0964-8305(00)00052-4 Danso
47. Danso D , Chow J, and Streita WR. Plastics: Environmental and biotechnological perspectives on microbial degradation. Applied and Environmental Microbiology. 2019; 85(19): e01095-19. DOI: 10.1128/AEM.01095-19
48. Jacquin J, Cheng J, Odobel C, Pandin C, Conan P, Pujo-Pay M, et al. Microbial ecotoxicology of marine plastic debris: A review on colonization and biodegradation by the plastisphere. Front Microbiol. 2019; 10: 865. DOI: 10.3389/fmicb.2019.00865
49. Urbanek AK, Rymowicz W, and Mirończuk AM. Degradation of plastics and plastic-degrading bacteria in cold marine habitats. Appl Microbiol Biotechnol. 2018; 102(18): 7669-7678. DOI: 10.1007/s00253-018-9195-y
50. Fathepure BZ. Recent studies in microbial degradation of petroleum hydrocarbons in hypersaline environments. Front Microbiol. 2014; 5: 173. DOI: 10.3389/fmicb.2014.00173
51. Repeta DJ, Ferrón S, Sosa OA, Johnson CG, Repeta LD, Acker M, et al. (2016). Marine methane paradox explained by bacterial degradation of dissolved organic matter. Nat Geosci. 9: 884-887. Available at: https://www.nature.com/articles/ngeo2837
52. Oberbeckmann S, and Labrenz M. Marine microbial assemblages on microplastics: Diversity, adaptation, and role in degradation. Ann Rev Mar Sci. 2020; 12: 209-232. DOI: 10.1146/annurev-marine-010419-010633
53. Bauer M, Kube M, Teeling H, Richter M, Lombardot T, Allers E, et al. Whole genome analysis of the marine Bacteroidetes' Gramella forsetii' reveals adaptations to degradation of polymeric organic matter. Environ Microbiol. 2006; 8(12): 2201-2213. DOI: 10.1111/j.1462-2920.2006.01152.x
54. Harshvardhan K, and Jha B. Biodegradation of low-density polyethylene by marine bacteria from pelagic waters, Arabian Sea, India. Mar Pollut Bull. 2013; 77(1-2): 100-106. DOI: 10.1016/j.marpolbul.2013.10.025
55. Zhang C, Li Y, Wang C, Niu L, and Cai W. Occurrence of endocrine disrupting compounds in aqueous environment and their bacterial degradation: A review. Crit Rev Environ Sci Technol. 2016; 46(1): 1-59. DOI: 10.1080/10643389.2015.1061881