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Chlorination as Drinking Water Disinfection Technique and Disinfection by Products: A Scientometric Analysis

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Chlorination as Drinking Water Disinfection Technique and Disinfection by Products: A Scientometric Analysis

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Abstract:

The Sustainable Development Goals (SDG) 2015, defined to achieve a better and more sustainable future, contains goal number 6 related to safe and affordable drinking water facility for all till 2030. The rural and remote areas in the developing countries predominantly face the scarcity of pathogen free drinking water leading to water borne diseases and deaths due to consumption of contaminated water indicating a need of advancement in the drinking water disinfection techniques. The paper discusses scientometric analysis of publication trends in chlorination as a popular disinfection techniques and research related to the Disinfection By Products (DBPs) that are produced due to the reaction between the disinfectant and naturally occurring organic matter in water.

The analysis of the existing SCOPUS database from year 2000 to 2020, indicates total of 1279 journal articles, 138 conference proceedings, 88 review papers, and 57 other documents, with the key words 'drinking water, disinfection, and chlorination'. As per the analysis, United States and China presented maximum publications related to drinking water disinfection using chlorination treatment. The analysis of literature also indicates that there is huge amount of literature related to the formation of alternative DBPs and their hazardous effects on human health. However, as per scopus database only three research documents are registered till date for the removal techniques of DBPs produced after the disinfection process, indicating a need of further research in this area. The literature also suggests the need to engender new technology or optimize the existing technology for minimizing the formation of DBPs.

Keywords: Bibliometric analysis, Drinking water, Disinfection techniques, Chlorination, Electro-chlorination and Disinfection by Products.

1. Introduction

The problems related to health and sanitation due to contaminated water being used for drinking purposes is more severe in the rural population (Wright et al. 2004). The non-availability of treated water mainly in rural areas is due to the high cost of treatment and inaccessibility to the centralized treatment facility. World Health Organization (WHO) estimates the burden of disease caused by unsafe water in collaboration with 14 leading research institutions, in 145 low- and middle-income countries. The study reports number of deaths in Africa and South-East Asia due to inadequate supply of treated drinking water. (Anon 2014).

The WHO also stated in 2017 that out of the total global population, 785 million people are even facing the deficiency of basic drinking-water services, and 2 billion uses contaminated water for drinking purposes which leads to diseases such diarrhoea, cholera, dysentery, typhoid, and polio. Half part of the globe's populace will be existing in water-stressed zones by 2025 stated by WHO (Water 2017). The inaccessibility of treated water is mainly due to its high cost, maintenance, and centralized treatment facility.

The disease-causing pathogens can be exterminated by the process of disinfection of water. Disinfection of drinking water on large scale is mainly carried out using Chlorination, Ultraviolet Light, and Ozone. The available literature on these three drinking water disinfection treatments is investigated from the available Scopus database to understand the trend of the research in respective drinking water disinfection treatment systems (figure 1). It has been observed that, 1849 documents are recorded from 2000 to 2020 for keyword "Drinking water" and "Disinfection" and "Chlorination". While for keywords "Drinking water" and "Disinfection" and "Ozone" has 744 research documents are recorded from 2000 to 2020. The number of documents are identified on Scopus database for "Drinking water" and "Disinfection" and "Ultraviolet Light" keywords are only 109. The data indicates that chlorination is more popular and widely used disinfection technique. Chlorination is the only process that maintains a presence of residual effect in water after the treatment also, continuing to disinfect the water during distribution, therefore chlorination is the worldwide popular method for water disinfection while ultraviolet light and ozone are more costly and not affordable to the low-income groups, furthermore, these both processes offer no residual treatment (Li, Zhu, and Ni 2011), (Hua, Bennett, and Letcher 2006).

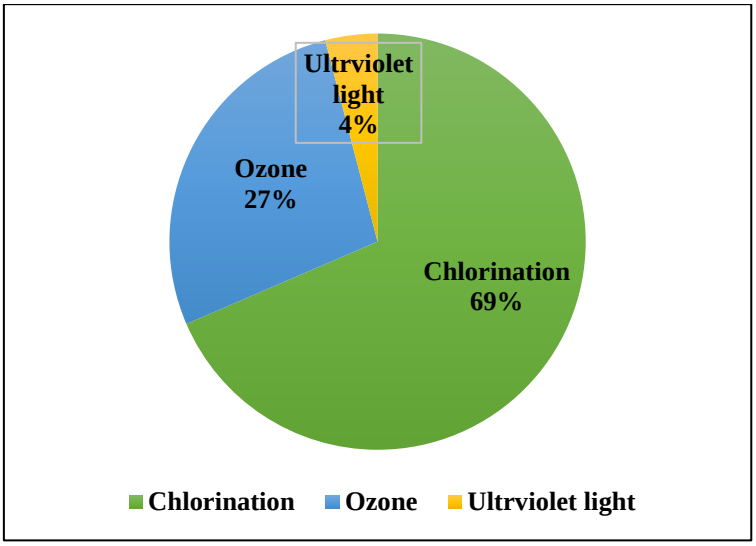

Fig. 1:*Percentage analysis of documents for chlorination, Ultraviolet light and Ozone treatment*

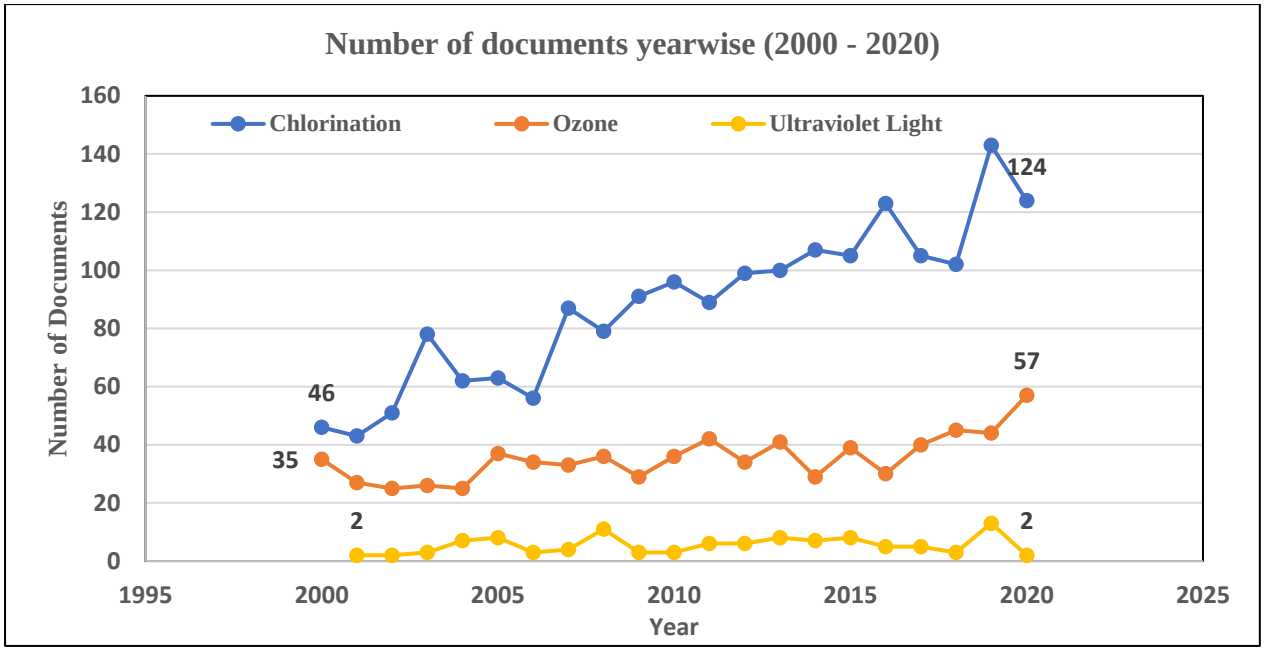

Fig. 2:*Number of documents of Chlorination, Ozone and Ultraviolet light treatment, year wise*

It has been observed from the Scopus database that the number of research documents in the area of Chlorination treatment are increased from year 2000 to year 2020 as sown in figure 2, whereas for ozone treatment the trend is increasing, but rise is very less in year 2020 in comparison with chlorination treatment. The figure 1, indicates that there are very few research documents recorded related to ultraviolet treatment of drinking water from year 2000 to year 2020 as compared to Chlorination and Ozone treatment and the trend is decreasing. The trend of research publication indicates that chlorination is more widely researched than the other two disinfection techniques. The reasons can be the low cost of treatment and residual effect provided by the chlorination. Literature indicates that many researchers are engaged to find out novel alternative for chlorination treatment that will tackle the drawbacks of chlorination like storage, transportation and disinfection by-product (DBP) formation (Boulay and Edwards 2001),(Branz et al. 2017),(Taylor, Ghernaout, and Ghernaout 2012),(Addendum and Third n.d.),(Wilson et al. 2018). One of such novel techniques is Electro-chlorination. In many of review papers it inferred that Electro-chlorination may reduce the drawbacks of chlorination process (Hrudey 2009),(Li and Mitch 2017),(Pressman et al. 2010),(Ghernaout 2018),(Saha and Gupta 2018).

Nearly all the disinfection techniques produce DBPs. The DBPs are the products generated after the disinfection process of water due to reaction between the organic matter present in water and disinfectant used. DBPs are carcinogenic and affect the human health badly. Figure 3 shows the number of documents published from year 2000 to 2020 related to the DBPs generated after different disinfection techniques. From the pie chart it observed that for keywords DBP and Chlorination treatment has highest number of publications than ozonation and ultraviolet light. Around 885 papers are recorded from year 2000 to 2020 for keyword DBP and Chlorination. In addition, there are some problems like storage and handling, safety, and transportation related to the disinfectants.

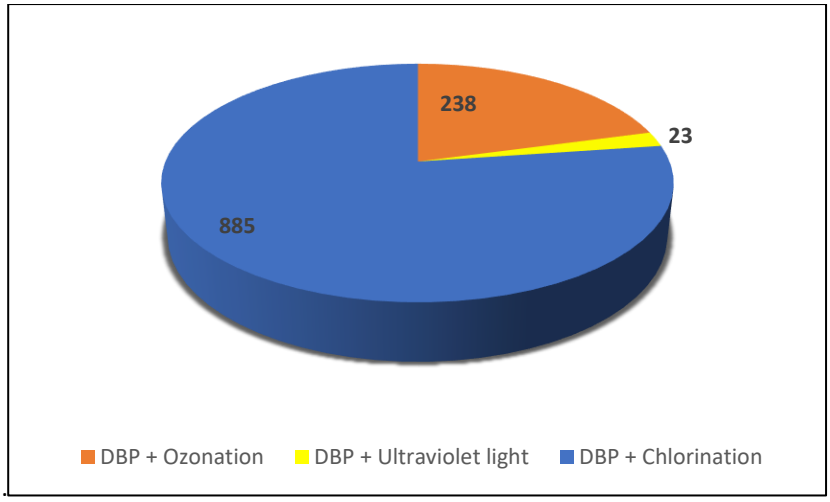

Fig. 3: *Share of Scopus publications for DBP and different disinfection techniques*

2. Data collection and methodology

The Scopus database is used to collect the literature involving articles, conference proceedings and reviews from 2000 to 2020. As discussed in the previous section, the widely used treatment technique to disinfect drinking water from past years is chlorination. The keywords used to look for research abstracts, titles and keywords in the database. are "Drinking water" and "Disinfection" and "Chlorination"

Two sets of keywords are compared on the basis of existing and novel drinking water treatment technologies. One set of keywords related to current treatment system i.e., "Drinking water" and "Disinfection" and "Chlorination" and other set of keywords based on novel treatment technique i.e., "Drinking water" and "Electro-chlorination" are used to look for research abstracts, titles and keywords in the database. The search is further refined for English language and including subject areas like environment, chemistry, engineering, chemical engineering and material science from year 2000 to 2020.

The raw data obtained for "Drinking water" and "Disinfection" and "Chlorination" showed total of 1556 records and for "Drinking water" and "Electro-chlorination" are only 7 documents, after refining the database. 'Results analysis' function in the Scopus is then used to statistically analyse the data, in terms of publications per year, research institutions, and countries. The document type considered for the study is confined to the articles, conference papers, reviews.

3. Bibliometric analysis and results

3.1 Year wise basic growth trend

The detailed bibliographic analysis from Scopus database is carried out for chlorination treatment to know the research trend in this field. Total 1556 documents are recorded on Scopus for keywords "Drinking water" and "Disinfection" and "Chlorination" and for data limited to English language and for subject areas corresponding to environmental science, chemistry, engineering, chemical engineering and material science from year 2000 to 2020. From the analysis it shows that from 2000 to 2020, the trend of research documents is increasing. 31 research papers are documented in year 2000 and trend increased to 132 documents recorded in year 2019. While in year 2020, 117 documents are published.

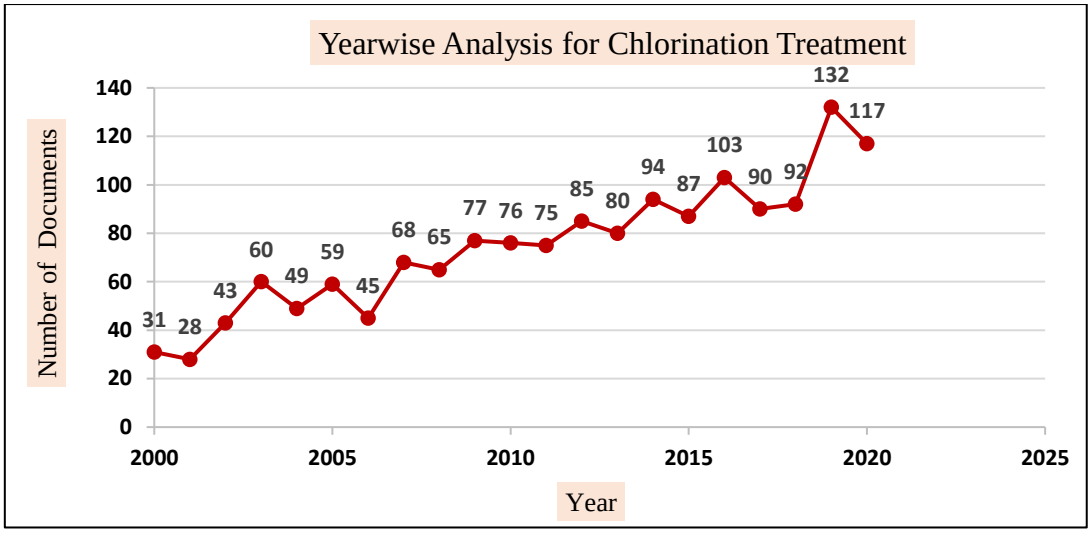

Fig. 4: *Year wise analysis of documents for Chlorination treatment*

Out of all these documents "Occurrence, genotoxicity, and carcinogenicity of regulated and emerging disinfection by-products in drinking water: A review and roadmap for research" research paper is highest cited document. The review article is published in Mutation Research journal in 2007. It is inferred from the research documents available on Scopus database that the chlorination process provides a residual effect which is the major advantage of the chlorination treatment (A et al. 2008),(Author 2007). Chlorination is cheaper than ozonation and ultraviolet processes and hence it is used worldwide than these two methods. (Baxter 1995),(Taflin 2006),(Wnlfe and Po 1990).

The disadvantages of chlorination treatment are recently emerging from the experience of past chlorination treatment systems and these disadvantages recently concluded in many publications. Disadvantages of chlorination treatment incorporated in research documents are - as chlorine is toxic gas its storage and handling on mass scale is risky. The leakage of gas may lead to severe accidents and such mishaps also happened in past years near Mumbai port and Jamshedpur. If chlorine stored for long time it corrodes the storage containers. Transportation of chlorine also a big problem because chlorine is corrosive and toxic gas. Skilled supervision is necessary, as small increase in residual chlorine may affects the human health. If chlorine store for long time, then it started to form a chlorate which reduces the disinfection effect (Boulay and Edwards 2001),(Hrudey 2009).

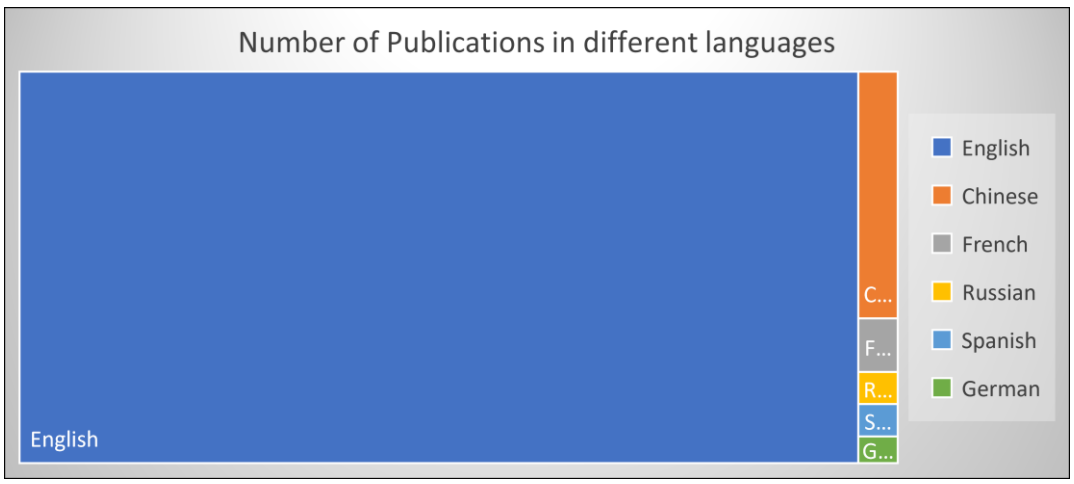

Fig. 5: *Number of publications in different languages*

The publications in area of drinking water disinfection using chlorination treatment are highest for English language amongst all other languages (Figure 5).

The novel technologies for disinfection of the drinking water that has been emerged in recent years are Deep-Ultraviolet light-emitting diodes technology (DUV-LEDs) with a water waveguide (WW) (Matsumoto, Tatsuno, and Hasegawa 2019), Inductively Coupled Plasma System (Desmiarti et al. 2018), Nanobubble Technologies (Atkinson et al. 2019), Bioanalytical approach (Lundqvist et al. 2019), Ultraviolet light-emitting diode reactors (UV-LEDs) (Disinfection 2019) and Electro-Chlorination (Riyanto and Agustiningsih 2018).

Very few publications are available in Scopus database for the above mentioned novel technologies The electro-chlorination process is more cost effective and comparatively more researched novel disinfection technique (Ghernaout, Alghamdi, and Ghernaout 2019),(Jung et al. 2007),(Ghernaout 2018),(Ghernaout and Ghernaout 2010). And hence inline to chlorination treatment, bibliographic analysis of Electro-chlorination treatment conducted to understand the research vogue of new technique. For set of keywords "Drinking water" and "Disinfection" and "Electro-chlorination", only 7 documents are identified on Scopus database. From figure 3 it has been recognized that very few research articles are published in the field of electro-chlorination treatment till 2020. The first research article is published recently in year 2010 and after that 3 documents are recorded in year 2017 and after that 1 document in year 2018,2019 and 2020 respectively. Very few study papers are based on actual pilot plats that are working in real scenario and thus have a large scope to study in this area.

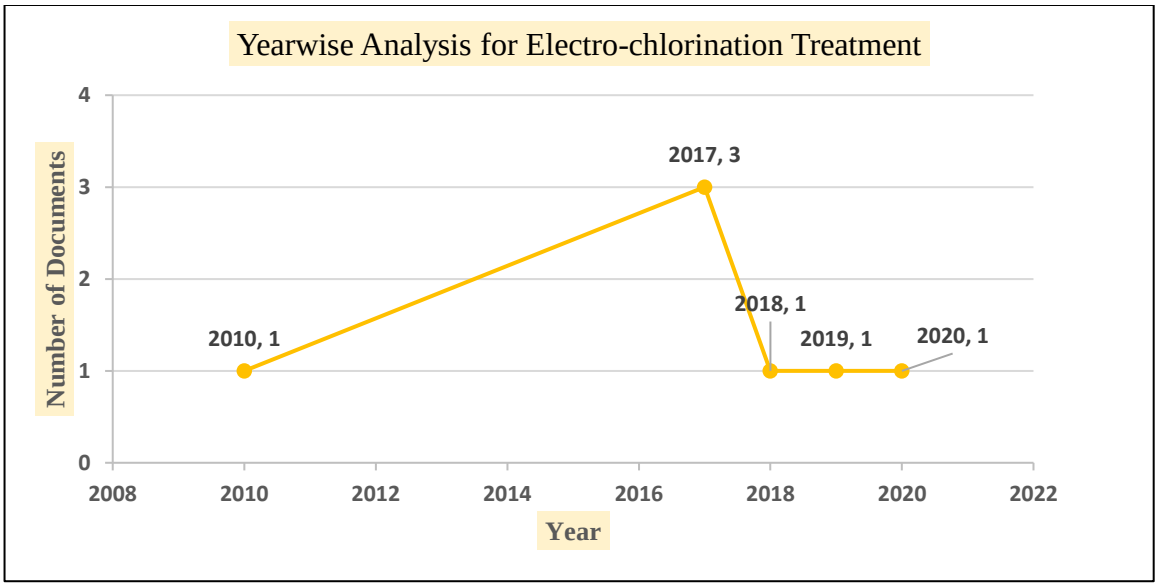

Fig. 6: *Year wise analysis of documents for Electro-chlorination treatment*

The data for number of records for different types of DBPs are collated from Scopus website from year 2000 to 2020.The most recognized DBPs like Trihalomethane, Chlorite, Chloral hydrate, Haloketones, halogenated acetic acids (HAA's), Chlorinated phenols and Halogenated acetonitrile's are assessed.

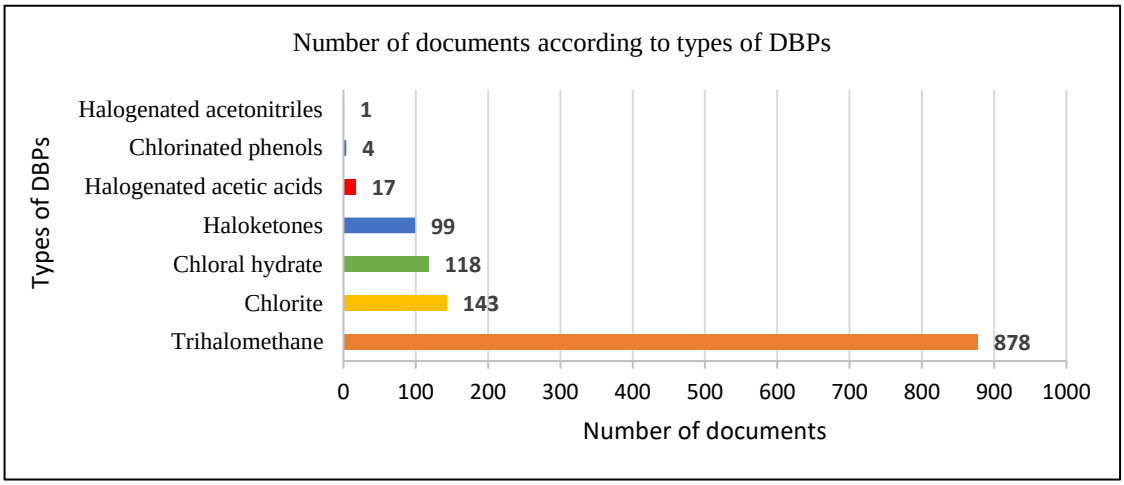

Fig.7: *Number of documents according to types of DBPs*

From the bibliometric analysis, it is evident that maximum number of documents recorded in Scopus are for Trihalomethane DBP (Figure 7). After trihalomethane, chlorite and chloral hydrate have 143 and 118 publications (Figure 7) respectively. While very few research studies are available on DBPs like Chlorinated phenols and Halogenated acetonitrile's (Figure 7).

The present bibliography paper provides detailed analysis of the research in the area of disinfection and disinfection by product to emphasis on the need of research for safe, affordable and sustainable disinfection process.

3.2 Type of publications

Bibliometric analysis is used as a systematic method to strengthen the research trends in drinking water treatment technologies globally based on the results of Scopus database.

Table 1:The types of publications in drinking water chlorination treatment.

Publication Type	Number of publications
Article	1279
Conference paper	138
Review	88
Other	51

Source: www.scopus.com (retrieved on 16th January 2021).

Table 2:The types of publications in drinking water Electro-chlorination treatment

Publication Type	Number of publications
Article	7

Source: www.scopus.com (retrieved on 16th January 2021).

The data obtained helped to evaluate the growth trend and contribution of a research field from different countries, institutions, categories, journals and researchers.

3.3 Subject area analysis

Number of research publications in the arena of chlorination and Electro-chlorination process are maximum in the field of Environmental Science. After environmental science, chemistry, engineering, chemical engineering and material science subjects also included the topic of drinking water disinfection (figure 8).

Overall, 1388 documents are recorded under Environmental science subject for disinfection using chlorination and 387,209,123,43 are accepted in the subject of chemistry, engineering, chemical engineering and material science respectively.

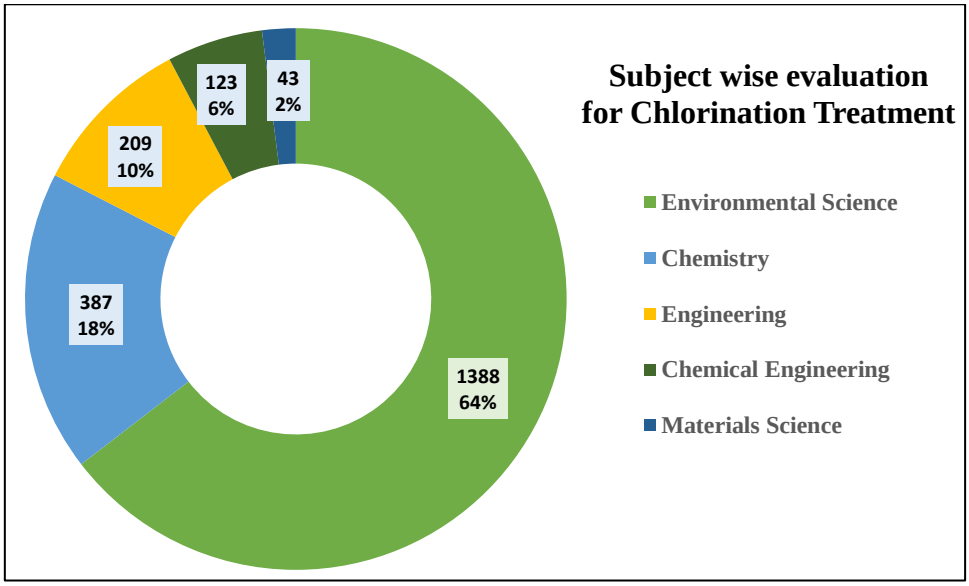

Fig. 8: Subject wise evaluation for chlorination treatment

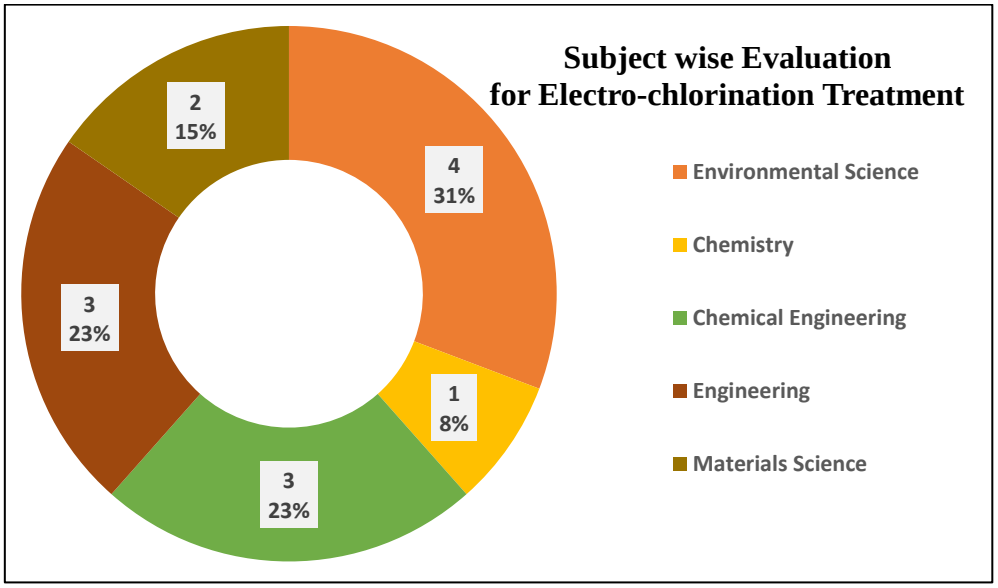

Fig. 9: Subject wise evaluation for Electro-chlorination treatment

3.4 Analysis of Journals

The top 10 journals with high publication number for chlorination treatment are enlisted in table 3 along with the cite score. The water research and Journal of environmental science and technology, published 241 and 130 papers each, in the mentioned domain.

Table 3:Name of Journals for drinking water treatment - Chlorination

Rank	Name of Journal	Cite Score	Number of Publications
1.	Water Research	14.5	241
2.	Environmental Science and Technology	12.6	130
3.	Chemosphere	8.8	93
4.	Science of Total Environment	8.6	81
5.	Water Science and Technology: Water Supply	1.5	68
6.	Journal of Hazardous Materials	13.1	42
7.	Journal of Water and Health	2.8	38
8.	Chemical Engineering Journal	0.125	35
9.	Water Science and Technology	2.9	33
10.	Environmental Science and Pollution Research	4.9	24

Figure 10 describes the publication pattern year wise in the top five journals, from 2000 to 2020. From year 2000, till 2019, Water Research journal is leading with highest publications for many years with cite score of 14.5. In the year 2020, Science of Total Environment has highest record of 15 documents with cite score of 8.6, while water research journal has record of 14 publications in year 2020 with same cite score of 14.5. Both the Water Research journal and Science of Total Environment journal belong to Elsevier publishing.

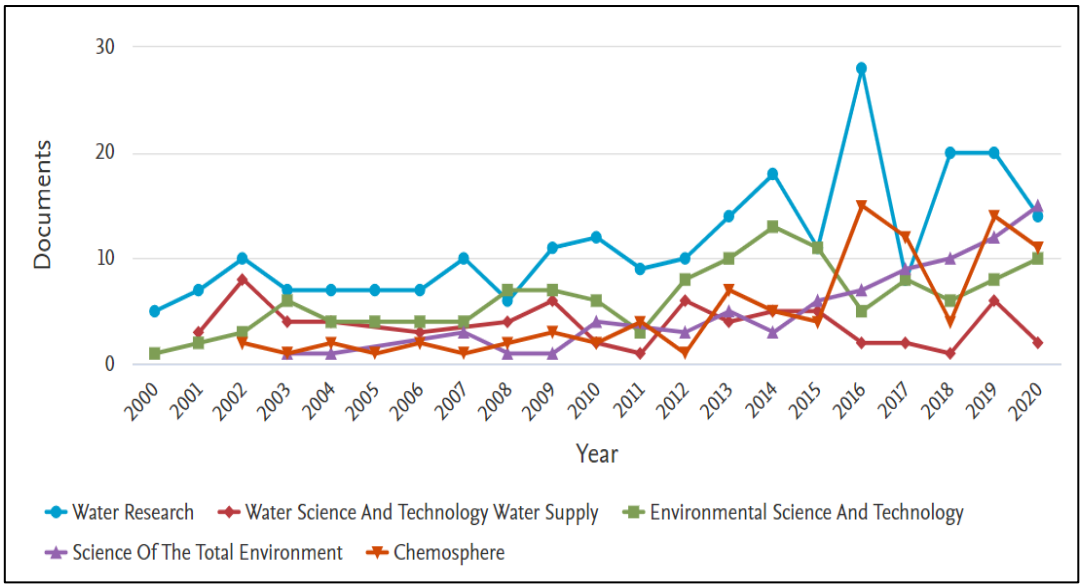

Fig. 10: *Number of documents per year in top five journals for chlorination*

In similar way, the number of publications in all journals for drinking water electro-chlorination treatment are shown in table 4 with their cite score. Total 7 documents identified for electro-chlorination treatment are published in 6 journals. Out of 7 research papers, 2 documents are recorded in the Ionics journal having cite score of 3.3.

Table 4: Name of Journals for drinking water treatment – Electro-chlorination

Rank	Name of Journal	Cite Score	Number of Publications
1.	Ionics	3.3	2
2.	Chemical Engineering Communication	2.8	1
3.	Desalination and Water Treatment	2.7	1
4.	International Journal of Environmental Research and Public Health	3	1
5.	Water Research	14.5	1
6.	Water (Switzerland)	3	1

Year wise, number of publications in each of the journal are presented in figure 11. The first research study basis on drinking water electro-chlorination treatment is published in year 2010 in Desalination and Water Treatment journal with cite score of 2.7. In year 2017 and 2018, 2 articles are recorded in Scopus database in Ionics journal. While in recent year 2020, 1 document published related to electro-chlorination in Water Research journal having cite score of 14.5.

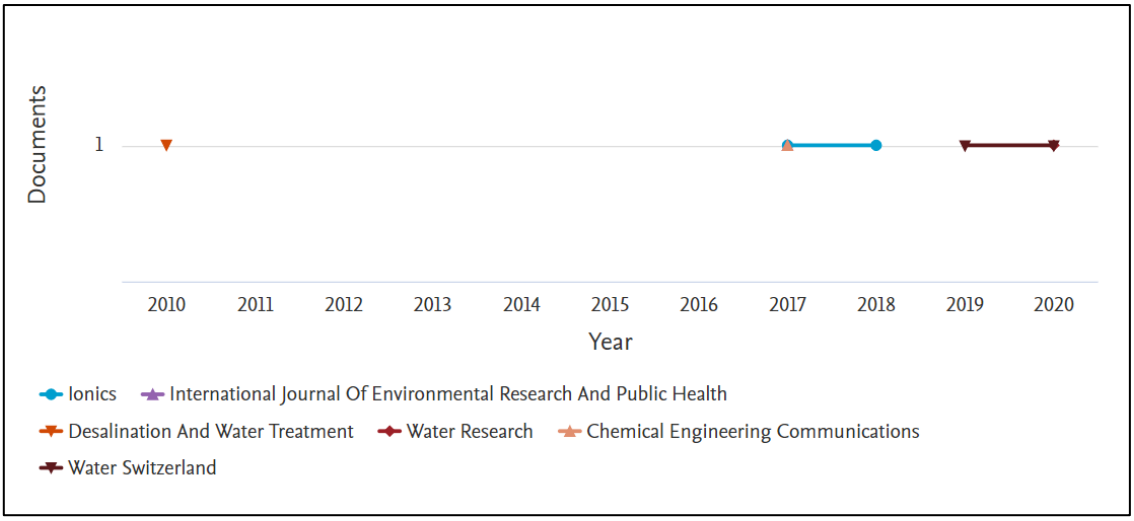

Fig. 11: *Number of documents per year in top five journals for Electro-chlorination*

3.5 Country wise analysis

The rules and regulations for safe and clean drinking water are stringent in developed countries than developing and undeveloped countries. From figure 12 it observed that the research in the field of drinking water treatment for chlorination process is higher in developed countries like United States, Canada, United Kingdom, Germany etc. While average investigations taking place in the developing nations. From figure 12 it observed that research related to drinking water in African countries is less even though these countries lacking from basic drinking water facility.

From year 2000 to 2020, the top most countries contributing in the research regarding to chlorination treatment for drinking water disinfection are United States, China and Canada.

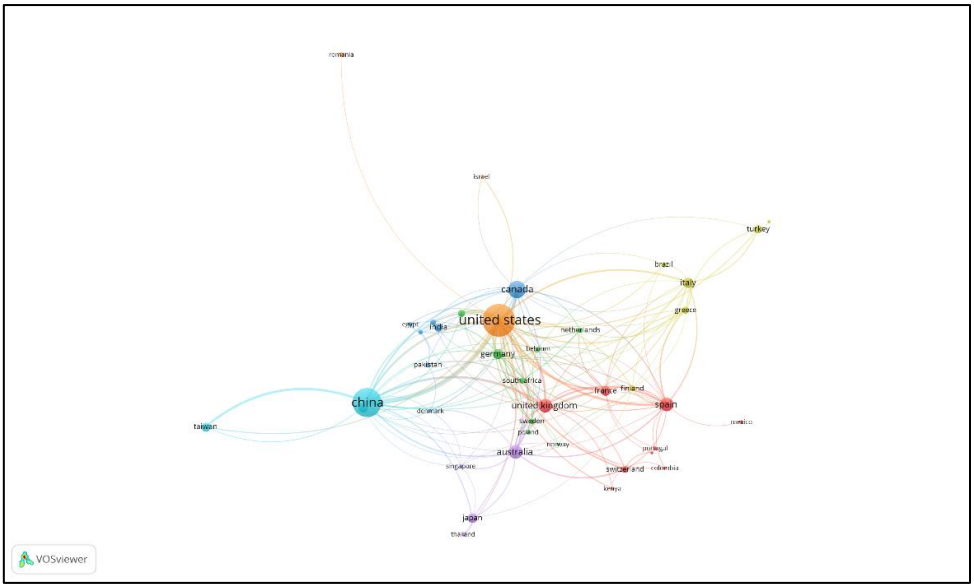

Fig. 12: *Country wise, number of documents for Chlorination treatment*

Also, country wise publications from year 2000 to 2020 is studied for new technology electro-chlorination that overcome problems of chlorination treatment as discussed in introduction. For keywords “Drinking water” and “Electro-chlorination”, total 7 documents are recorded on Scopus data limit to English language from year 2000 to 2020. From figure 13 it observed that India is top most country with 6 publications in the area of electro-chlorination treatment. From Germany, 3 publications in year 2017, 2019 and 2020 are documented. From detailed study of these 7 documents, it observed that, out of 6 publications from India 3 research papers are based on actual pilot plants that are installed in India but research study is conducted in Germany and studied by German authors.

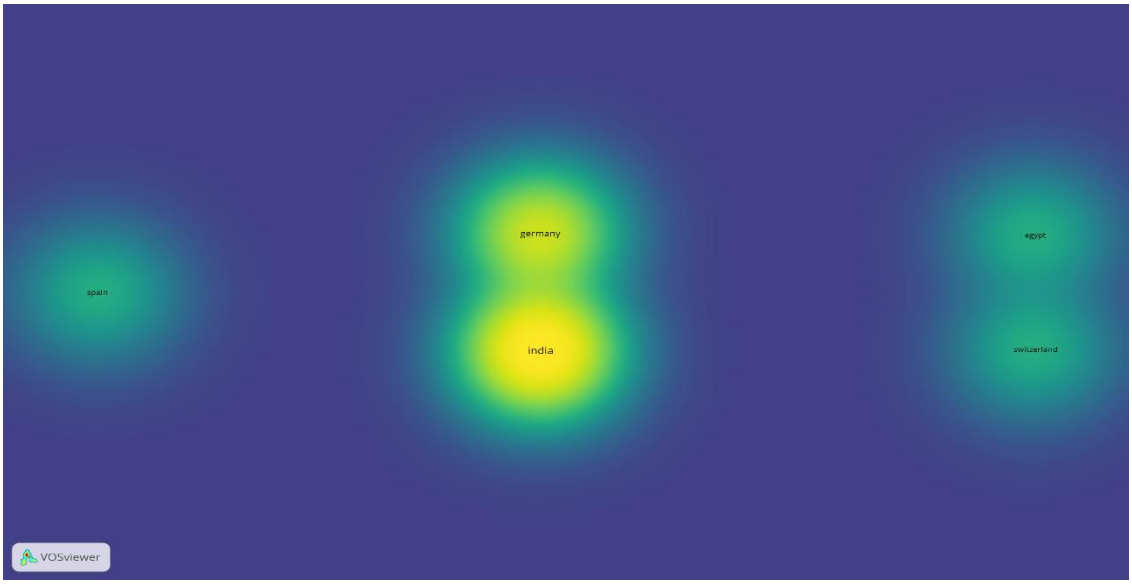

Fig. 13: *Number of documents Country wise for Electro-Chlorination treatment*

Remaining 3 documents are virtuously from India and study based on electro-chlorination lab scale model. Shaha and Gupta, authors from India investigated lab scale study in year 2017 and 2018. And research on electro-chlorination is still going on as lots of limitations in pilot and lab scale need to be verified for different water characteristics.

The country-wise analysis for the DBP generation due to chlorination process is illustrated in figure 14.

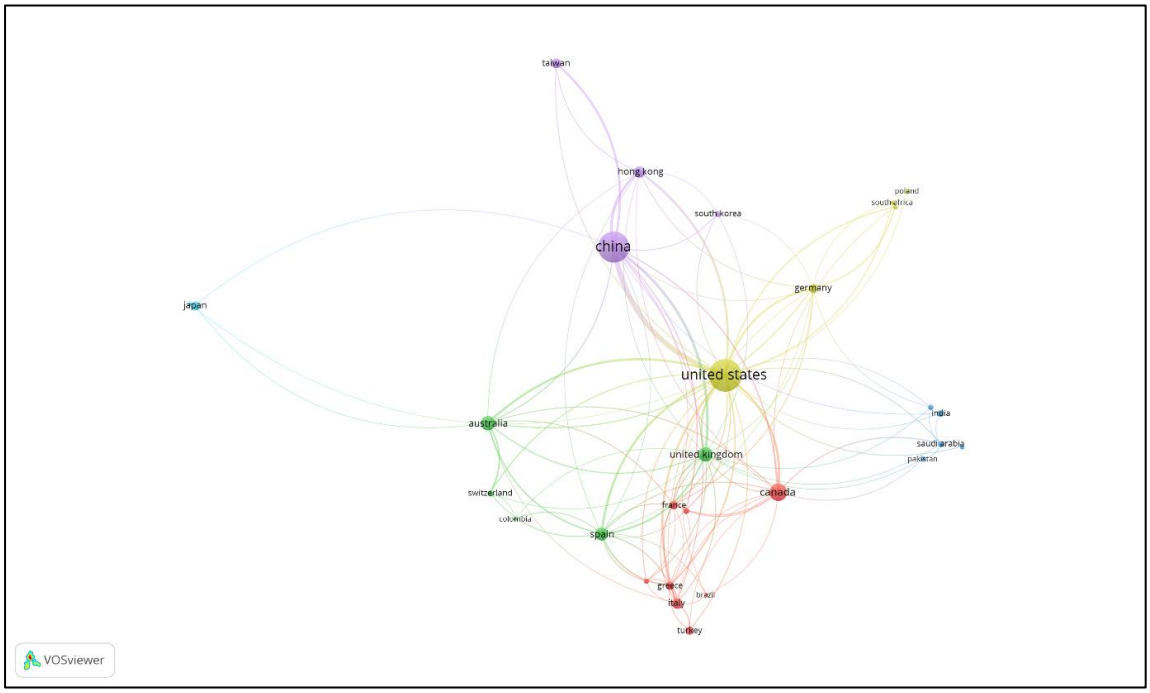

Fig. 14: *country-wise analysis for the DBP generation due to chlorination process*

Figure 14 shows that, United states and china has highest publications in the field of Chlorination and DBPs. United States contributed 580 number of publications in the field of DBP and chlorination. After united states and China, countries like Canada, United Kingdom, Germany, Australia are also published the documents in the similar area.

3.6 Authorship analysis

Figure 15 shows the author's contribution analysis in the area of drinking water disinfection using chlorination treatment. It helps in identifying the influence of some prominent authors in the area. The data shows that Chu W has highest number of publications in this domain. Chu W has 46 publications, while Rodriguez M. J., Gao N and Krasner S W has 40, 34 and 34 publications respectively.

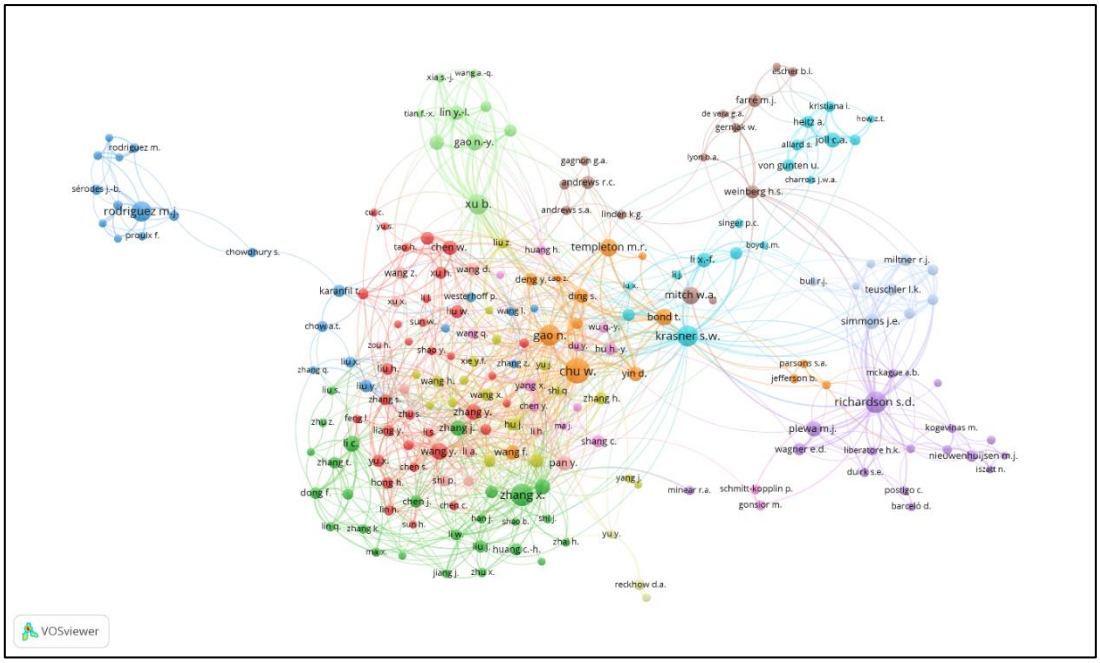

Fig. 15: *Authorship analysis for disinfection of drinking water using Chlorination*

While, in the field of disinfection using electro-chlorination, Otter P, Malakar p, Gold maier and Benz F has highest publications.

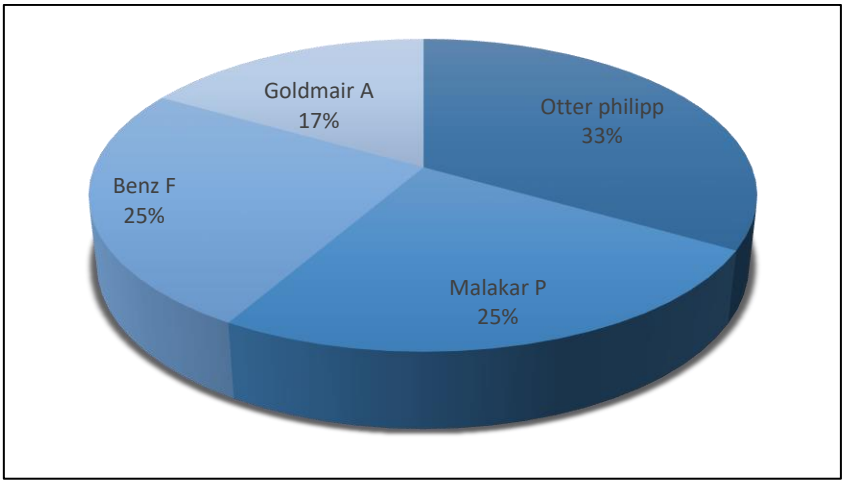

Fig. 16: *Authorship analysis for disinfection of drinking water using Electro-Chlorination*

The Scopus database is also analysed for the documents on DBPs. The bibliography analysis for keyword DBP and Chlorination is carried out to know the country-wise, authorship and keyword wise analysis of published documents.

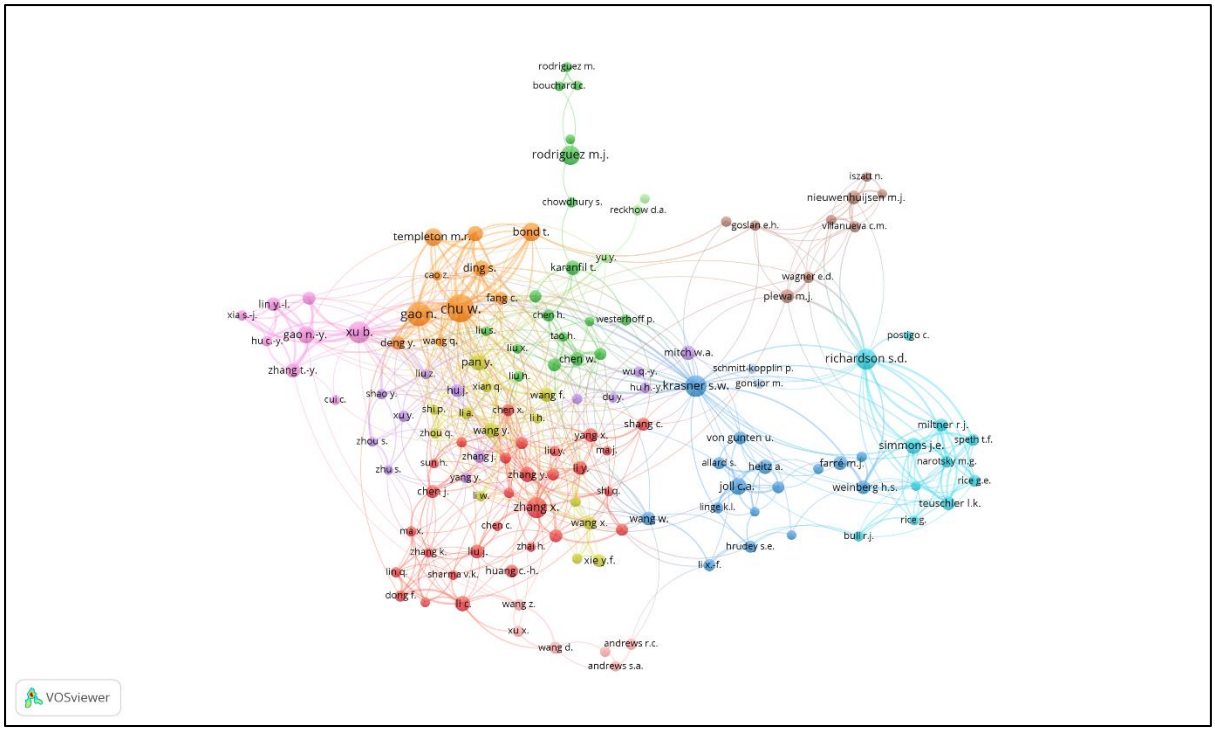

Fig. 17: *Authors contributed in area of DBP formation due to chlorination*

Figure 17 shows the author's contribution analysis in the area of drinking water disinfection using chlorination treatment. It helps in identifying the influence of some prominent authors in the area. The data shows that Chu W has highest number of publications in this domain. Chu W has 46 publications, while Rodriguez M. J., Gao N and Krasner S W has 40, 34 and 34 publications respectively.

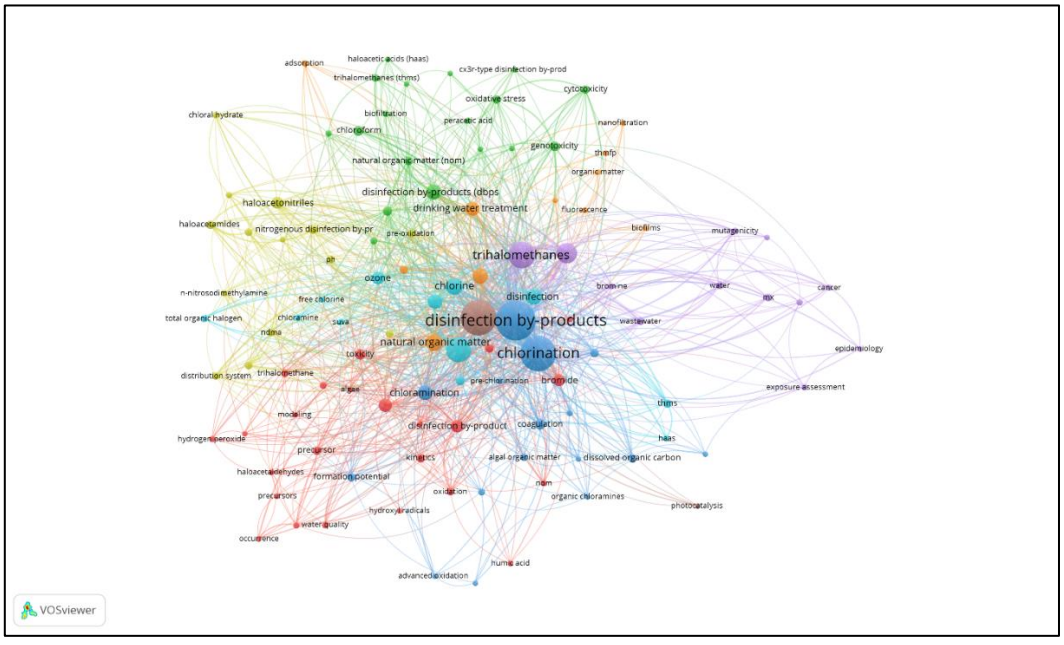

Fig. 18: *Most used keywords in area of DBP generation by chlorination disinfection*

Figure 18 shows the keywords used by the authors in the documents published in year 2000 to 2020. The most used keywords are disinfection by product, chlorination and trihalomethane. From the figure 18 it observed that Trihalomethane is one of the DBP that has been studied by many authors.

DBP formation is one of the major disadvantages of current disinfection treatment and need to address this issue as it affects human health. To save the human lives DBP removal is one of major area to do further research.

4. Conclusions

The increased awareness for clean water and sanitation leading to a requirement of more efficient, economical, safe and sustainable treatment systems for drinking water disinfection treatment has resulted in the growing trend in the numbers of publications on drinking water disinfection technologies in the past two decades suggesting that a significant amount of research is being carried out in this field indicating research development in this field.

Chlorination is widely used treatment for disinfection of water and has maximum number of publications in Scopus database than ozone and ultraviolet techniques. The number of documents recorded on Scopus for the carcinogenic Disinfection By Products (DBPs) formed during chlorination process are highest amongst all other disinfection techniques. It is observed from the analysis that among the several types of DBPs that has been identified, the maximum research has been incorporated on Trihalomethane.

As per Scopus database of publications extracted, English is the primary language used in scientific documents on chlorination and DBPs. Analysis revealed that Water Research, is the leading journal, publishing in the sector of drinking water disinfection technology and DBPs. Significant contributors to the research are China (26.4%), United States (16.9%), Spain (6.4%), India (5.7%), and Canada (4%). Researchers all over the world are continually working to come up with enhanced technologies for applications in drinking water remediation. It has gradually evolved from the core subject "Environmental science "and "Engineering" to a multi-disciplinary approach, combining chemistry, energy, material science, biochemistry and material sciences resulting in a further tremendous rise in the research in drinking water treatment, with development of new concepts and treatment technologies.

The literature indicates that there are very few novel technologies in the field of disinfection. Electro-chlorination has comparatively more number of publications and advantages than other novel technologies. India and Germany are top two countries for publication in field of Electro-chlorination. While for chlorination treatment United States, China and Canada are top tree countries for document publications on Scopus. The present study indicates the need of further research in the field of new disinfection technologies that would minimize the production of harmful DBP generation.

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