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Application of Artificial Intelligence and Machine Learning in Desalination: A Bibliometric and Review Study

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Abstract – The water scarcity and importance of desalination in recent years motivated us to do a bibliometric and overview study on this subject. This study has been performed concerning artificial intelligence and machine learning that can be addressed as guidance for researcher who want to explore this field. The research growth of desalination, most productive, countries are investigated. The highly influential papers and top keywords are also introduced. This paper summarizes the growth structure of research in applying artificial intelligence and machine learning in desalination during the last 28 years and provides a concise bibliometry.

***Keywords*:** Desalination, Artificial Intelligence, Machine Learning, Bibliometric study

1. Introduction

Due to the limited and low access to fresh water [1], desalination and water treatment processes are of great importance for the optimal use of saline water resources and their conversion into fresh water. Desalination describes a process that aims to obtain freshwater from saline water resources, such as brackish water or seawater. Desalination has become a reliable water supply process since its evolution in the 1950s, with improved technical and economic feasibility [2]. Thanks to the advancement of online scientific databases including Scopus, Web of Science and ScienceDirect, today, more than ever, we have access to scientific papers and researches, and access to scientific papers is no longer a challenge. However, a new challenge facing researchers is how to analyze these papers and scientific information. One of the tools with which we can analyze a vast amount of scientific documents is VosViewer. Analysis with VosViewer software provides topic polarization, the topic trend in recent years, highly cited authors, highly cited documents, documents relations, countries, and authors collaborations. Since this is a relatively new and developing topic, it is necessary to conduct a statistical study and scientometric analysis to give a general and comprehensive view to the interested researchers. No statistical study and scientometric analysis have been performed on in the point of view of artificial intelligence so far. Statistical analysis or scientometrics provide us with an overview and structure of a field of research and a guide and motivation for future research. Therefore, we considered it necessary to examine this issue in this work. The paper structure. In Section 3, the most cited works between 1993 to 2020 will be addressed. The rest of the paper is structured as follows: Section 2 describes the process of data collection and the methodology used in this paper. Detailed and extensive bibliometric analysis is performed in Section 3, and Section 4 deals with the overview study and section 5 is devoted to discussion and conclusion.

2. Data collection and methodology

The bibliometric data was gathered from Scopus that is referred to as the widest repository. The keywords used in the advanced search query of the Scopus, with the following structure, are desalination, machine learning, artificial intelligence, artificial neural networks (ANNs), genetic algorithm and neural networks

(TITLE-ABS-KEY(desalination) AND
(TITLE-ABS-KEY("Machine learning") OR

TITLE-ABS-KEY("Artificial Intelligence") OR
TITLE-ABS-KEY("artificial neural networks (ANNs)") OR
TITLE-ABS-KEY("genetic algorithm") OR
TITLE-ABS-KEY("Neural networks")))

The search was performed on 1st January 2021, and several tags such as author, title, country, citation, author affiliation, etc., are considered. The above advanced search query of the Scopus results in 513 documents published from 1993 to 2020, and categorized in Table1.
In this paper, various performance indicators have been introduced for the bibliometric analysis. TP stands for Total Papers, which is the total number of publications from the source, TC stands for Total Citations, which is devoted to the publication's total number of citations. CPP stands for Citations per Paper that is the total number of received citation counts divided by total publications. In most of the Tables, R denotes the Rank of the case.

Table 1: Distribution of document types based on advanced search query of section 2 in Scopus.

Document Type	*Total numbers*	*Contribution %*
Article	438	85.38
Conference paper	39	7.60
Conference Review	24	4.68
Review	7	1.37
Book Chapter	3	0.59
Book	1	0.20
Note	1	0.20

3. Bibliometric analysis

This section is devoted to the bibliometric results for the various performance parameters such as research growth, most productive and highly cited authors, discipline wise analysis, top journals, country-wise analysis, institution wise analysis, highly influential papers, and topmost keywords in the field of desalination and machine learning.

3.1. Research growth

The desalination in point of view of machine learning has been started since 1993 and gaining rapid attention since 2009. Fig. 1 shows the total number of publications and citations per year in Scopus. In Scopus, the first publications on artificial intelligence and desalination, came out in 1993 with five papers. Later, it increased till it reached the maximum of 63 in 2018 and 2020. The total number of citations count per year in Scopus is also shown in Fig. 1. According to Scopus, the maximum number of citations came in 2016 with the TC count of 584. In the subsequent years, citation count decreased to 326 in 2017, followed by an increase to 527 in 2018 and then decreased to 2020. This citation reduction is because these publications are comparatively more recent; the citation counts will undoubtedly increase in the coming years. From the publications and citation analysis, we can see that this field is very prone to increasing growth. Within 28 years, there are 513 documents in Scopus. Moreover, the citation counts will naturally increase concerning the number of publications in this indexing platform.

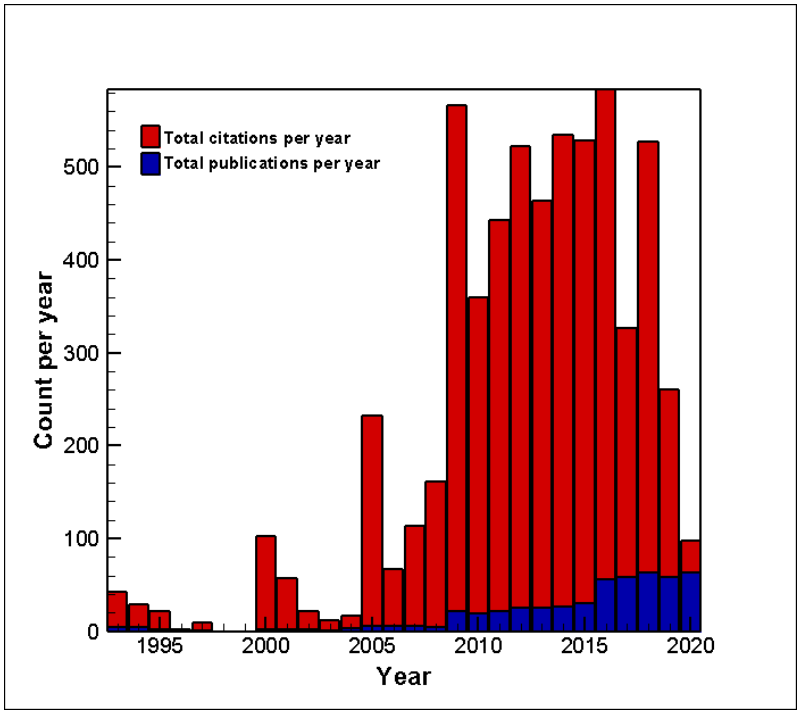

Fig. 1: The total number of publications per year in Scopus.

3.2. Most productive and highly cited authors

The most productive authors for Scopus are extracted and sorted out based on the number of publications. The authors with the same number of publications count, then the ranking is given based on the TC. The top 15 list of most productive authors is shown in Table 2. Amidpour is the highest contributor with 11 publications in Scopus. In Scopus, Amidpour m. is followed by Lee s. and Alazba a.a. with 10 and 10 publications. Some authors have the same TP, which were ranked based on their TC. The most influential authors were sorted based on total citations received in all the papers. Amidpour m., who was the most productive author with 11 papers, is also at the first spot among the most influential authors with 400 citations in the Scopus. Fig. 2 illustrates the most influential authors' links in which node size shows the citation point of view's effectiveness.

Table 2: Top 15 most productive authors in Scopus.

R	*Authors*	*TP*	*TC*	*CPP*
1	Amidpour m.	11	400	36.36
2	Lee s.	10	140	14
3	Alazba a.a.	10	131	13.10
4	Hamza k.	10	28	2.80
5	Nassef a.o.	9	26	2.89
5	Saitou k.	9	26	2.89
6	Kim j.h.	8	78	9.75
7	Wang j.	7	116	16.57
8	Yoo c.	6	187	31.17
9	Mujtaba i.m.	6	103	17.17
10	Al-gobaisi d.m.k.	6	44	7.33
11	Badreddin e.	5	45	9
11	Gambier a.	5	45	9
12	Hernández j.a.	5	19	3.8
13	Choi y.	5	12	2.40

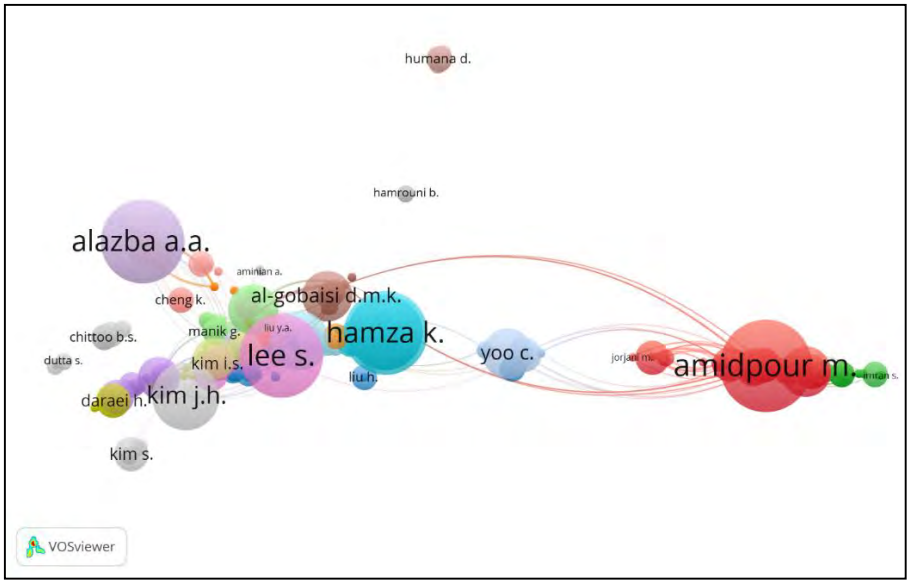

Fig. 2: The most influential authors link.

3.3. Country-wise analysis

The top 15 most productive countries in terms of the number of publications, are presented in this section. Table 3 shows the order of the countries sorted by TP, taking into account the TC and CPP. In Scopus, as the most productive country in this field, Iran has the first position in the list with 129 TP and the first position from TC's viewpoint. Fig. 3 shows the links of the most influential countries in the field of Desalination and Machine Learning. As mentioned in previous subsections, the size of nodes illustrates the citation count.

Table 3: Top 15 countries publishing work on Desalination and Machine Learning in Scopus.

R	*Countries*	*TP*	*TC*	*CPP*
1	Iran	129	1555	12.05
2	China	61	439	7.20
3	India	50	525	10.50
4	United States	42	330	7.86
5	South Korea	41	468	11.41
6	United Kingdom	24	565	23.54
7	Saudi Arabia	23	165	7.17
8	Egypt	21	157	7.48
9	Spain	19	382	20.11
10	United Arab Emirates	18	158	8.78
11	Australia	17	294	17.29
12	Malaysia	15	82	5.47
13	Canada	14	264	18.86
14	Turkey	13	56	4.31
15	Italy	12	265	22.08

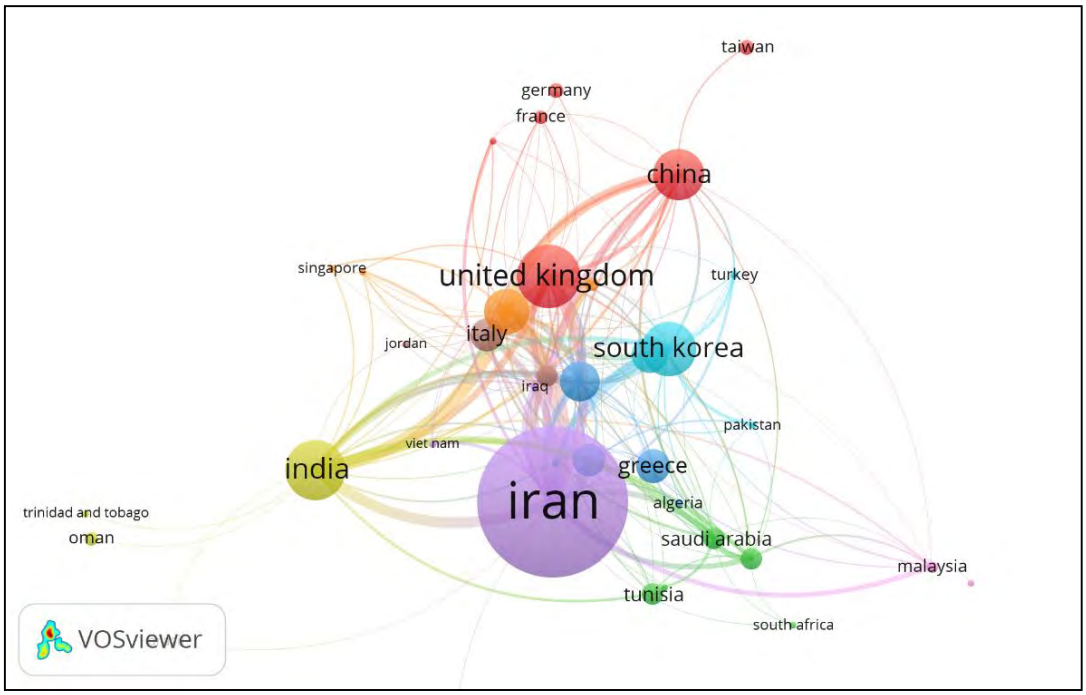

Fig. 3: The most influential country links.

3.4. Topmost keywords in Scopus

This section is devoted to the top keywords used by the authors in their papers. The VOSviewer, as the most widely used information visualization software, is employed for selecting the top keywords. Fig. 4 illustrates the connected network of the most common keywords indexed in Scopus.

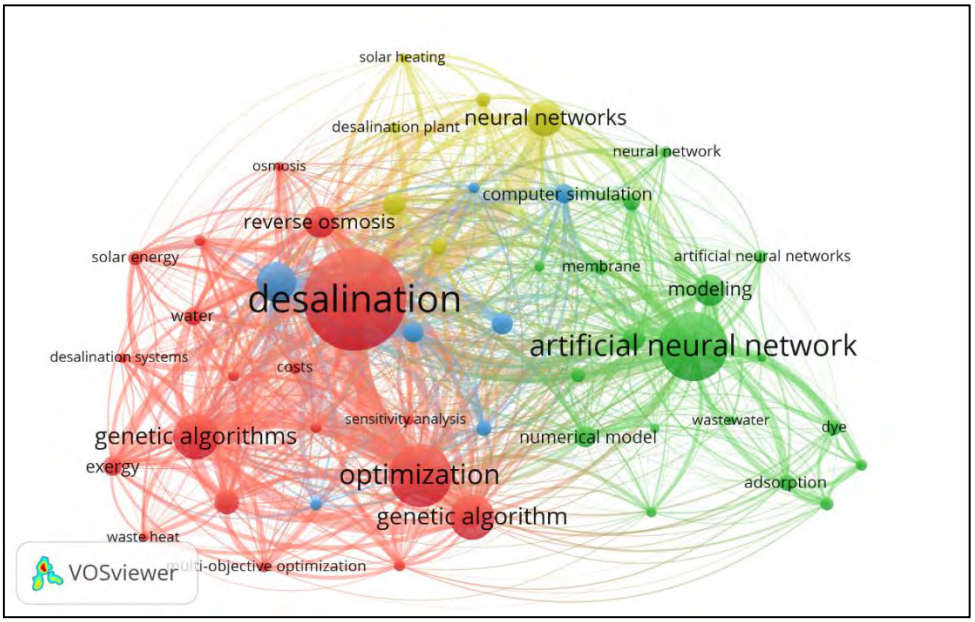

Fig. 4: The most popular keywords in Scopus.

3.5. Top 15 highly influential papers

This section lists the top 15 most highly cited papers from 1993 to 2020 in Scopus.
Table 4 gives the list of the fifteen highly influential papers ranked by most citations in Scopus. This table also contains the name of the authors, year of publication, and publishing source.

Table 4: The most influential papers from 1993 to 2020.

R	*Authors &Year*	*Title*	*Source title*	*TC*
1	Kalogirou S. [3]	Solar Energy Engineering	Sol. Energy Eng.	275
2	Karavas C., et al. [4]	A multi-agent decentralized energy management system based on distributed intelligence for the design and control of autonomous polygeneration microgrids	Energy Convers. Manage.	135
3	Khayet M., et al. [5]	Artificial neural network modeling and response surface methodology of desalination by reverse osmosis	J. Membr. Sci.	129
4	Sayyaadi H., Saffari A. [6]	Thermoeconomic optimization of multi-effect distillation desalination systems	Appl.Energy	117
5	Ahmadi P., et al. [7]	Thermoeconomic multi-objective optimization of a novel biomass-based integrated energy system	Energy	103
6	Guria C., et al. [8]	Multi-objective optimization of reverse osmosis desalination units using different adaptations of the non-dominated sorting genetic algorithm (NSGA)	Comput. Chem. Eng.	103
7	Sadrzadeh M., et al. [9]	Separation of lead ions from wastewater using electrodialysis: Comparing mathematical and neural network modeling	Chem. Eng. J.	93
8	Najafi B., et al. [10]	Exergetic, economic and environmental analyses and multi-objective optimization of an SOFC-gas turbine hybrid cycle coupled with an MSF desalination system	Desalination	90
9	Vrkalovic S., et al. [11]	Model-free sliding mode and fuzzy controllers for reverse osmosis desalination plants	Int. J. Artif. Intell.	87
10	Al-Alawi A., et al. [12]	Predictive control of an integrated PV-diesel water and power supply system using an artificial neural network	Renew. Energy	83
11	Bourouni K., et al. [13]	Design and optimization of desalination reverse osmosis plants driven by renewable energies using genetic algorithms	Renew. Energy	82
12	Koutroulis E., Kolokotsa D. [14]	Design optimization of desalination systems power-supplied by PV and W/G energy sources	Desalination	78
13	Khayet M., Cojocaru C. [15]	Artificial neural network modeling and optimization of desalination by air gap membrane distillation	Sep. Purif. Technol.	77
14	Abbas A., Al-Bastaki N. [16]	Modeling of an RO water desalination unit using neural networks	Chem. Eng. J.	76

15	Xia G., et al. [17]	Thermodynamic analysis and optimization of a solar-powered transcritical CO2 (carbon dioxide) power cycle for reverse osmosis desalination based on the recovery of cryogenic energy of LNG (liquefied natural gas)	Energy	74

4. Overview Detail

With analysis data of fourty high cited papers in VosViewer and study connection between keywords, three main categories were found: Optimization, Energy and Desalination system. The most important category was optimization because this category includes 27 papers of 40 papers or in other words 67.5 % of papers belong to this category and the second important category is the desalination system with 21 papers with a share of 52.5%.

5. Discussion and conclusion

In this paper, bibliometric analysis has been conducted in an attractive field of desalination that is desalination in point of view of Artificial Intelligence. The bibliometric analysis helped us to explore the structures and development in this area. The repository Scopus aided us in gathering 513 documents in this field. The results have shown that Iran, China, and India are the leading countries in Desalination-Artificial Intelligence technology. Amidpour m. is the most productive author in the Scopus database with a TP of 11 and is most influential in Scopus with a TC of 400. The bibliometric analysis in this paper provided the intrinsic structure of the publications on Desalination-Artificial Intelligence. Then, the visualization of the most common keywords in Desalination-Artificial Intelligence is presented. After the bibliometric analysis, top papers ranked based on total citations are analyzed from 1993 to 2020. The impediment of this study is that the bibliometric study gives the number of papers and their citations. In any case, numbers speak to the amount, yet citations do not connote quality. Also, we have covered the generally utilized Scopus for bibliometric study, be that as it may, some different sources incorporate open-access journals. Along these lines, more exploration with other indexing databases
such as Google Scholar and WOS could be considered as a future extent of this investigation [1]

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