



## Research Paper

## A Glimpse into Dr. Nidal Hilal's Scientific Achievements

Mohamed Khayet<sup>1,2,\*</sup>, Ersin Aytaç<sup>1,3</sup><sup>1</sup> Department of Structure of Matter, Thermal Physics and Electronics, Faculty of Physics, University Complutense of Madrid, Avda. Complutense s/n, 28040, Madrid, Spain<sup>2</sup> Madrid Institute for Advanced Studies of Water (IMDEA Water Institute), Avda. Punto Com, N° 2, 28805, Alcalá de Henares, Madrid, Spain<sup>3</sup> Department of Environmental Engineering, Zonguldak Bülent Ecevit University, 67100, Zonguldak, Türkiye

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## Highlights

- Dr. Nidal Hilal is a Global Network Professor with great experience in the academy.
- Desalination Journal is Dr. Hilal's most contributed source with 144 papers.
- Dr. Hilal has co-authored 10 or more documents with 26 scientists.
- Mohammad A.W. is the longest-time co-author of Hilal's publications (1997-2022).
- Depending on the author's keyword, "nanomaterials" is his recent trending topic.

## Graphical abstract



## Abstract

Since 1994, when he published his first scientific paper, Dr. Nidal Hilal has become a role model in the scientific community for his influential research works (articles, books, chapters in books, conferences, patents, etc.) and management (editor-in-chief, editorial board member, advisor, consultant, director of research centers, etc.). His research career has been focused mainly on, but not limited to, membrane engineering, membrane processes, and water research including desalination. Here we reveal Dr. Hilal's scientific contribution and impact in the fields of engineering and technology using bibliometric and text mining approaches, together with Orange Data Mining, Python, and R-Biblioshiny (Bibliometrix) tools. According to the dataset downloaded from the Scopus database, on January 1<sup>st</sup>, 2023, Dr. Hilal's h-index, and g-index were found to be 79 and 144, respectively; with a 9.88 % annual growth rate of publications. He has published documents in 97 different sources with 433 authors all around the world, and 2015 stands out as his most productive year. He has contributed mostly to scientific articles (287). The source listed with most of his publications is Desalination, where he served as Editor-in-Chief for 13 years increasing its impact factor by 451.2 %, from 2.034 in 2009 to 11.211 in 2021. He also published 8 books. Trending topic analysis of keywords reveals that for the past few years, he has focused on nanomaterials. Sentiment analysis shows that he is delivering good and upbeat news to all at a fairly high rate.

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## 1. Introduction

It is not easy to decide where to begin in presenting the personal and professional life of a scientist with a long and successful career such as

that of our colleague Dr. Nidal Hilal. Perhaps the most logical is to follow a chronological order. He was born on February 2<sup>nd</sup>, 1958, in Homs located 162

\* Corresponding author: khayetm@fis.ucm.es (M. Khayet)

km north of Damascus (Syria). The strategic and geographical location of this multicultural city with its easy access to the Mediterranean attracting overland trade from the Persian Gulf and Iraq, its diverse religious and ethnic communities, its long and rich history, and its humble past due to unpredictable wars, and its irrigation system, the first of its kind in modern Syria, have made it a center of agriculture and industry such as oil and sugar refineries. Perhaps these forged Dr. Hilal's first steps into the Science branch and then forced him to move to Europe, United Kingdom (UK), in 1978 to continue his academic career. He graduated from Bath University with a bachelor's degree in chemical engineering in 1981. He then started to work as a process supervisor in the petroleum industry (1981–1984). From the University of Wales, Swansea, he received his M.Sc. in Advanced Chemical Engineering in 1985 and his Ph.D. in Chemical Engineering in 1988. At the same university, between 1989 and 1998 he continued working as a postdoctoral researcher and research fellow. Then he moved to the United Arab Emirates (UAE) to work as an assistant professor in the Department of Chemical and Petroleum Engineering at UAE University (1998–2000). Between 2000 and 2001, he returned to the United Kingdom (Wales) to work as a senior research fellow in the Center for Complex Fluids Processing at the University of Wales, Swansea. Between 2001 and 2003, he was a senior lecturer at the University of Nottingham (UK), and between 2003 and 2005, he was a reader in Environmental and Mining Engineering at the same University. In 2002 he got the Post Graduate Certificate in Academic Practice from the University of Nottingham, and in 2005 the University of Wales awarded him a senior doctorate (Doctor of Science) degree in recognition of his outstanding research contribution in the fields of water process engineering and membrane science and technology. He was registered for multiple duties at the University of Nottingham until 2010: i)- 2003-2010 Founding Director of the Centre for Clean Water Technologies; ii)- 2005-2010 Professor (Personal Chair) at the School of Chemical and Environmental Engineering; iii)- 2005-2010 Head of the Green Chemicals and Water Technologies Division, Faculty of Engineering; iv)- 2007-2010 Deputy-Head, School of Chemical, Environmental, and Mining Engineering. After 2010, he had three different duties at Swansea University: i)- Up to 2012, he was the head of the Energy and Environment division; ii)- up to 2013, he directed the Chemical and Environmental Engineering; and iii)- up to 2020, he was the chair of Water Process Engineering and Director of the Centre for Water Advanced Technologies and Environmental Research (CWATER) [1]. Between 2012 and 2014, he was assigned as the Chief Academic Officer and Acting Provost, at Masdar Institute of Science and Technology, Abu Dhabi (UAE). In 2014–2015, he worked at the Qatar Foundation (Qatar) in two positions: i)- Chief Scientist and leader of the Water Security Challenge, and ii)- Senior Research Director, Environment and Water Sciences and Technology. In 2017-2018, he returned to the UAE to serve as Dean of the College of Engineering at the University of Sharjah. From 2018 to the present, he has been assigned as Director of the NYUAD Water Research Center, New York University-Abu Dhabi Campus (UAE), and Global Network Professor of Engineering, New York University (USA) [2]. From 2020 to the present he has been an Emeritus Professor in Engineering, at Swansea University (UK) [3].

His research interests are broad and include the discovery of novel and cost-effective solutions in the fields of membrane technology, water treatment, and nano-water, including colloid engineering, desalination, and atomic force microscopy nano-engineering applications. As a respected scientist, he was invited to be a member of important professional societies like the European Membrane Society (EMS), the European Desalination Society (EDS), the International Desalination Association (IDA), the International Water Association (IWA), and the Mohammed Bin Rashid Academy of Scientists (UAE). Besides, he has professional qualifications from highly reputable organizations. He is a Chartered Engineer (CEng) (UK), a Member of the European Federation of National Engineering Associations (Euro. Ing.) (BE), a Member of the Institution of Chemical Engineers (MIChemE), an Elected Fellow of the Institution of Chemical Engineers (FIChemE) (UK), and an Elected Fellow of the Learned Society of Wales (FLSW) (UK).

His academic productivity has made Dr. Hilal one of the world's leading scientists. Google Scholar currently ranks him first in the fields of membrane separation, nanofiltration, and membrane distillation, as well as second in reverse osmosis and seventh in desalination [4]. Clarivate has placed him within the top 0.1% of scientists worldwide on its list of Highly Cited Researchers 2022 [5]. On research.com, in the field of engineering and tech, he has been ranked 169<sup>th</sup> in the world and first in the UAE. He was recently named the most cited author in the journal *Desalination* and *Journal of Water Process Engineering* [6]. Moreover, he was listed among the most Notable Alumni of Swansea University [7] and included in the list of notable and famous 21<sup>st</sup>-century British Engineers [8]. In addition, his achievements were also recognized by governments through various awards. In 2005 he won the

Kuwait Prize of Applied Science from the Kuwait Foundation for the Advancement of Sciences [9]. In the same year, he was awarded the Emir of Kuwait with the Certificate of Appreciation. In 2018, he got the Appreciation from the ruler of the Emirate of Sharjah and a Member of the Federal Supreme Council of the UAE. In 2020 he was awarded by the Learned Society of Wales for Excellence in Engineering and Technology (UK) with the Menelaus Medal [10] and named on the 2020 New York University Faculty Honor's List.

As a worldwide recognized researcher, Dr. Hilal has not only published a large sum of manuscripts and received a quite high number of citations, but he contributes to various journals editorials as a member of editorial boards of 10 journals (*Nanomaterials*, *Advances in Colloid*, and *Interface Science*, *Case Studies in Chemical Engineering*, *Desalination*, and *Water Treatment Journal*, etc.) and as advisory board of *Membranes*, as honorary editorial consultant of the *Journal of Arab Water World*, and as guest editor of a special issue of *Advances in Colloid and Interface Science*. He was the Editor-in-Chief of *Desalination* for 13 years (2009-2021) and managed the increase in the impact factor of this journal by 451.2 % from 2.034 in 2009 to 11.211 in 2021. Besides, he has intense referee activity in the world's leading journals such as *Nature*, *Science*, *Langmuir*, *Water Research*, *Journal of Membrane Science*, *Chemical Reviews*, *Colloids and Surfaces A.*, and many more. In general, he is on the referee panel of more than 50 international journals.

One of the most important areas where information is distributed and shared is at scientific conferences. In this sense, he delivered more than 60 plenaries, keynotes, and invited lectures at various institutions throughout the world. Dr. Hilal has made a great contribution to conferences, not only by presenting his scientific studies but also as an organizer, member of scientific committees, and chair of at least 19 conferences. Some of them are: Member of the Scientific Committee for the 4<sup>th</sup> International Conference on Mediterranean Water Resources, Algeria 22-24 March 2008; Chairman of a membrane fouling session at the "1<sup>st</sup> Oxford Water and Membranes Research Event," July 2-4, 2006, Oxford, UK; Chairman of a session in the Euromed 2008 International Conference, "Cooperation among Mediterranean Countries of Europe and the MENA Region," Session 11 SWRO III, November 9–13, Dead Sea, Jordan; and Chair of the 4<sup>th</sup> International Conference on Desalination Using Membrane Technology, organized by Elsevier in December 2019, Perth, Australia. In addition, he has been on the advisory panels and expert committees of more than 18 conferences.

Dr. Hilal had formed many consortia and made collaborations all around the world (e.g. 5 research partners from Massachusetts Institute of Technology (MIT) and Masdar Institute of Science and Technology; 11 academic and industrial partners on an EU project; 7 research partners from a Marie Curie TOK project; 2 research partners from the Petroleum Institute in the United Arab Emirates (UAE), and other research partners from Universiti Kebangsaan Malaysia, Jordan University of Science and Technology, Sultan Qaboos University in Oma, University of Leeds, Ukrainian Academy of Science, Loughborough University, University Complutense of Madrid, and Dow Corning (USA) among others).

Dr. Hilal is not only a dedicated research scientist but also a person who takes pride in passing on his knowledge and guidance to future generations. He has supervised more than 40 Ph.D. students, more than 50 M.Sc. students, and more than 20 visiting researchers, who are serving society in many areas of science and engineering. Dr. Hilal has acted as an internal examiner for 32 Ph.D. theses from international institutions including the University of Oxford (UK), University of Cambridge (UK), University of Surrey (UK), University of Nottingham (UK), University of Bradford (UK), Loughborough University (UK), University of Wales (UK), Nanyang Technological University (Singapore), Rovira-i Virgili University (Spain), University of Salford (UK), and Melbourne University (Australia). He is still supervising Ph.D. students and postdoctoral researchers. Additionally, Dr. Hilal has improved the scientific abilities of his students by imparting the latest developments in the scientific world through lectures he gives at his institutions. His vast expertise and perceptive observations have piqued the interest of national and international media, especially in informing the public about desalination, access to clean water, and sustainability. The *Telegraph*, *BBC Radio 4*, *Vision Magazine*, *Arab Economics* newspaper, *Sky News Arabia*, *The National*, and *Water Online* are among the media organizations with which he gave an interview.

In this study, we examine Dr. Hilal's scientific contribution using bibliometrics and text mining (TM). Bibliometric analysis involves quantifying the exposure and effect of a given research publication, journal, or researcher using a variety of indicators, including the number of citations and impact factors. Bibliometric analysis can be used to assess the caliber and importance of research on a given topic, to recognize influential researchers and emerging trends, and to guide funding and publication choices. Scientometric methods can be applied to many areas, such as the scientific, technological, and medical fields. A variety of methods and databases,

including Web of Science, Scopus, and Google Scholar, can be used to perform bibliometric analysis [11, 12].

The extraction of pertinent and helpful information from unstructured text data is a process known as "text mining," often referred to as "text data mining" or "text analytics" [13]. It involves the application of natural language processing (NLP), machine learning (ML), and data mining (DM) methods to analyze massive amounts of text and uncover insightful trends. ML is a discipline in computer science that aims to give machines the ability to learn using various data collection, storage, and processing techniques [14, 15]. This learning process is carried out thanks to the samples delivered to the machines. According to the model taught to the machines, they become capable of responding to new data using the knowledge they have gained from examining samples. In this way, machines can perform tasks such as classification, clustering, time series prediction, regression, etc. [16-18]. Moreover, one can find a paper in the scholarly database in the graphical abstract created based on an ML architecture [19]. Supervised learning, unsupervised learning, and reinforcement learning are the main branches of ML [20]. Natural Language Processing is an interdisciplinary field concerned with understanding and exploiting languages to facilitate human-computer interaction [21]. The synergistic convergence of breakthroughs in machine learning, signal processing, cognitive computing, and big data heralded the emergence of large-scale data-driven methods in NLP [22]. Sentiment analysis, topic modeling, and information retrieval are just a few of the many uses for text mining. This is frequently used to draw important conclusions from massive amounts of unstructured text data in different fields. It is a process that involves a series of steps, such as preprocessing the text data (tokenization, stemming, and lemmatization), creating a representation of the text data (using a bag of words model or a word embedding), and using ML algorithms to find patterns and extract valuable information [23-25]. A word cloud (tag cloud) shows the frequency and significance of terms in a text through a visual representation. Each word's magnitude in a word cloud corresponds to how frequently it appears in the text. It is commonly used to condense and depict the information in a text or collection of documents [26]. Sentiment analysis is the process of identifying and extracting qualitative information from text data using machine learning and natural language processing techniques. It is frequently employed to evaluate a speaker's or writer's mood or sentiment toward a specific subject or issue [27]. The emotion analysis task in NLP is about analyzing the user's subjective text with emotional color or determining whether the text supports a specific point of view. The first approach of emotion analysis was based on an emotion vocabulary. This approach does not need pre-labeling of the text and has low emotion categorization accuracy. Yet, as machine learning has grown in popularity, a number of machine learning classification algorithms have made significant advances in the field of natural language processing [28]. Despite the specifics that may differ, the overall purpose is the same: to identify and recognize the sort of emotion expressed by the target document, such as happiness, rage, or surprise [29].

In this paper, we reveal the importance in research progress of hard work, effective dedication, cutting-edge innovation, wide communication, operative networking, high-quality skills, and wise training of next-generation scientists among others, through the scientific career of Dr. Hilal, using bibliometric and text mining methods together with the Orange Data Mining Tool, Python and R-Biblioshiny (Bibliometrix) software.

## 2. Dataset and Methodology

### 2.1. Dataset

The used dataset was obtained from the Scopus database on January 1<sup>st</sup>, 2023. Compared to other databases, Scopus offers access to a greater number of indexed documents (articles published in journals, books, and chapters published in books) together with a variety of sorting, ranking, and refining options. Another reason for choosing Scopus was that the search with the author name "Nidal Hilal" (Scopus Author Identifier: 7006606410) included more data documents than other databases [30]. The other followed refinement criteria were language ("English") to overcome compatibility issues in text mining approaches and the publication stage ("Final"). Eventually, the documents that were not indexed in any database were added manually to the dataset. The resulting dataset includes 439 documents.

### 2.2. Methodology

For the scientometric analysis, R-Bibliometrix (Biblioshiny tool) was used. This tool was created by Massimo Aria and Corrado Cuccurullo, and it is considered among the most popular software for bibliometrics [31]. The equations and assumptions for data analysis are as follows:

$$\text{Annual growth rate (compound)}(\%) = \left( \left( \frac{ND_f}{ND_i} \right)^{\frac{1}{(Y_f - Y_i)}} - 1 \right) \times 100 \quad (1)$$

where  $ND_i$  is the number of publications of the initial year ( $Y_i$ ) and  $ND_f$  is the number of publications of the final year ( $Y_f$ ) [32].

Scientific works with two or more authors from different institutions are referred to as international co-authorship (collaboration index) defined as [33, 34]:

$$\text{International Co-authorship} = \frac{\text{Authors of multi-authored articles}}{\text{Multi-authored articles}} \quad (2)$$

The co-authors per document value is calculated as [35];

$$\text{Co-authors per document} = \frac{\text{Authors appearances}}{\text{Number of documents}} \quad (3)$$

The document average age value can be calculated as the total age of the publications in the dataset divided by the number of publications:

$$\text{Document average age} = \frac{\text{Total age of the documents in the dataset}}{\text{Number of documents}} \quad (4)$$

The average number of citations of each publication that is published in a specific domain can be calculated as [36]:

$$\text{Average citation per document} = \frac{\text{Total times cited value of documents}}{\text{Number of documents}} \quad (5)$$

The  $h$ -index of an author/journal-level statistic means that each publication has at least  $h$  citations [37]. The  $g$ -index indicates the top  $g$  publications that collectively obtained at least  $g^2$  citations within a set of publications sorted in decreasing order of received number of citations [38]. An alternate metric to the  $h$ -index is the  $m$ -index, which is computed by dividing a researcher's total number of publications by the total number of years since the first publication [39]:

$$m\text{-index} = \frac{h\text{-index}}{n} \quad (6)$$

where  $n$  is the number of years since the first publication.

Global citations are the total number of times a researcher, an article, or a journal has been cited in a body of literature that has been assembled and stored in bibliographic databases like Scopus, Web of Science, Google Scholar, etc. In contrast, the local citations track the number of citations of a given publication by other authors in the collected dataset [12, 40].

For the text mining analysis, Orange Data Mining Tool and Python were used. Since some documents have missing abstracts the text mining analysis was carried on 389 data points. Orange is a toolkit for data mining and machine learning that uses Python scripting and visual programming to analyze data [41]. Converting to lowercase and converting accent; tokenization; removing stop words, lexicon, numbers, and regular expressions; stemming and lemmatization steps, Oranges' text preprocessing widget was used. Tokenization is the process of dividing a long piece of text into tokens, which are smaller pieces of text like words, phrases, or symbols [42]. Finding a word's stem (root) is a primitive heuristic technique called stemming. This approach is based on trimming the word's non-root parts [43]. Tokens are reduced to a common form by means of a lemmatization procedure, which compares them to dictionaries [44]. Then, the preprocessed data was used for the word cloud method. For the word cloud method, Orange Data Mining Tool was used. The sentiment and emotion analysis were carried out with Python. For sentiment analysis distilbert-base-uncased-finetuned-sst-2-english model from the Hugging Face repository was used. distilbert-base-uncased-finetuned-sst-2-english is a pre-trained classification model that is fine-tuned based on DistilBERT-base-uncased and SST-2 and it achieved 91.3 % accuracy on the dev set [45]. The classification of emotions in text data was carried out with a pre-trained model by Hartmann named emotion-english-distilroberta-base. The model is a fine-tuned DistilRoBERTa-based checkpoint. It was trained on six diverse datasets and classified data into 7 emotions (anger, disgust, fear, joy, neutral, sadness, and surprise) [46]. Both sentiment and emotion models only work with the data points that has less than 512 tokens, so the process was carried out on 386 abstracts. The results of sentiment and emotion analyses are float values ranging from 0 to 1. A sentiment score close to 0 indicates a pessimistic text and 1 indicates an optimistic text. An emotion value close to 0 depicts a low-intensity emotion and close to 1 depicts a high-intensity emotion encountered.



### 3. Results and Discussion

The main information about the collected dataset, which is the summary statistics of key characteristics like the total number of publications, time span, sources for publications, indices (*h*-, *g*- and *m*-indexes), etc. are given in Fig. 1.

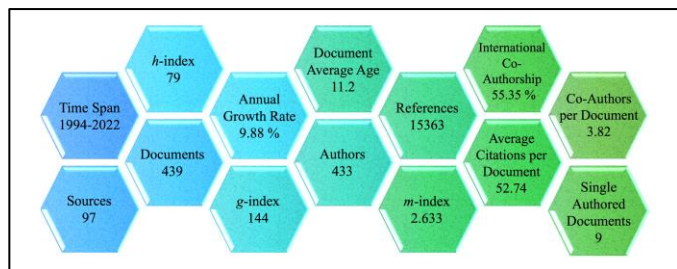


Fig. 1. Main information about Dr. Hilal's dataset downloaded from the Scopus Database.

The dataset covers Dr. Hilal's 29-year research period since 1994, when he published his first international article, until the end of 2022. During this time, he published 439 documents in 97 different sources with 439 researchers using 15363 references. His international co-authorship value (55.35 %) shows the broad collaborations with researchers from countries all around the world. His *h*, *g*, and *m* indices (collection-based impact) are 79, 144, and 2.633, respectively. These indicate that he is a highly influential scientist. His impact on science can also be verified by his average citations per publication value, which is 52.74. Dr. Hilal's annual growth rate of publications is 9.88 %. This can also be seen in his annual publications illustrated in Fig. 2.

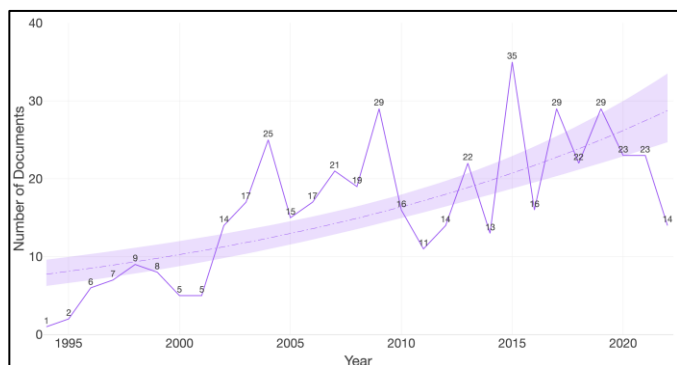


Fig. 2. Annual scientific production of Dr. Hilal.

In general, Dr. Hilal's contributions to science have continued since the beginning of his academic adventure in 1994. Nevertheless, 2015 stands out as the year in which his productivity reached its maximum with 35 published documents. The principal bibliographical categories present the most pertinent types or those that have the most documents on the topic. These include research articles, review articles, books, chapters in books, etc. Dr. Hilal's bibliographical categories can be seen in Table 1.

Table 1  
Bibliographical categories of Dr. Hilal's publications.

	Category				
	Article	Review	Book Chapter	Editorial	Book
Number of Publications	287	72	59	13	8

Table 1 is the most important proof of Dr. Hilal's productivity. Based on the collected domain, Dr. Hilal mostly published research articles (287). He has also published a good number of review articles (72), which is a good way of summarizing and synthesizing the research on a particular topic. Publication of scientific books is also important and decisive in promoting the exchange of knowledge and its transfer to a wider audience and the public. In this sense, Dr. Hilal published a total of 8 comprehensive books (5 of them are edited books) between 2009 and 2022 [47-54]: "Atomic force microscopy in process engineering: An introduction to AFM for improved processes and products" in 2009, "Membrane Modification: Technology and Applications" in 2012, "Membrane Fabrication" in 2015, "Boron Separation Processes" in 2015, "Membrane Characterization" in 2017, "Membrane-Based Salinity Gradient Processes for Water Treatment and Power Generation" in 2018, "Nanofiber Membranes for Medical, Environmental, and Energy Applications" in 2019 and "Osmosis Engineering" in 2021. In addition, the following two other books are in press at the time of writing this article: "Electrically Conductive Membrane Materials and Systems" and "Nanofiltration for Sustainability: Reuse, Recycle, and Resource Recovery".

He has also delivered many conference proceedings at international conferences. Some of them are; "Application of atomic force microscopy in the study of interactions of biological materials" in 2<sup>nd</sup> European Symposium on Biochemical Engineering Science (16-19 September 1998, Porto, Portugal), "Design parameters estimations in spouted beds, two and three dimensions" in Proceedings of the IASTED, Applied Simulation and Modelling (24-26 July 2000, Alberta, Canada), "Scale removal from Cow-hole tubing of oil and gas, utilizing high pressure water atomizers" in 19<sup>th</sup> Annual Meeting of the Institute for Liquid Atomization and Spray Systems (6-8 September 2004, Nottingham, UK), "Ultrafiltration of aqueous mixtures containing a polyelectrolyte and inorganic low-molecular weight salts" in 20<sup>th</sup> Conference of the European Colloid and Interface Society jointly organized with 18<sup>th</sup> European Chemistry at Interface Conferences (17-22 September 2006, Budapest, Hungary), "Hydrodynamics of particle-wall interaction: AFM study" in 30<sup>th</sup> Annual Meeting, Brazilian Society of Chemistry (31 May-3 June 2007, Sao Paulo, Brazil). Fig. 3 shows the distribution of documents by subject areas of Dr. Hilal's publications.

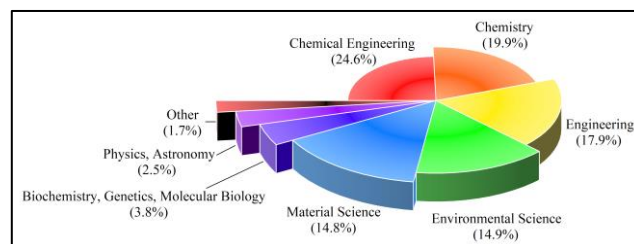


Fig. 3. Subject areas of Dr. Hilal's publications.

Taking into consideration his research fields (membrane engineering, membrane processes, and water research including desalination), Dr. Hilal contributed mostly to the areas of chemical engineering, chemistry, environmental science, and material science. The most relevant sources (top 10 journals) where he most frequently publishes his studies are indicated in Fig. 4.

As can be seen in Fig. 4, Dr. Hilal predominantly published in Desalination (144 papers). Journal of Membrane Science is the second journal where he normally published his research studies (30 papers), and the Journal of Water Process Engineering ranks third with 17 papers. Dr. Hilal has held different relevant academic positions in universities and institutions and has made fruitful scientific collaborations with research groups from all over the world as can be seen in Fig. 5 based on the most relevant affiliations in the dataset.

The first and relevant affiliation of Dr. Hilal with 361 published documents is Swansea University (University of Wales, Swansea). In fact, it is where he completed his master's and doctorate degrees, worked as a post-doctoral researcher, and taught as a researcher and lecturer for many years. Then, the University of Nottingham, where he got the Post Graduate Certificate in Academic Practice and held relevant academic positions, is his second-most relevant affiliation with 254 published documents. His current affiliation, New Yor University Abu Dhabi, ranks third just after the Universiti Kebangsaan Malaysia, with whom he has made strong research collaborations. The other institutions included in Fig. 5 only show the extent of the scientific collaborations carried out by Dr. Hilal since he did not officially work in them.

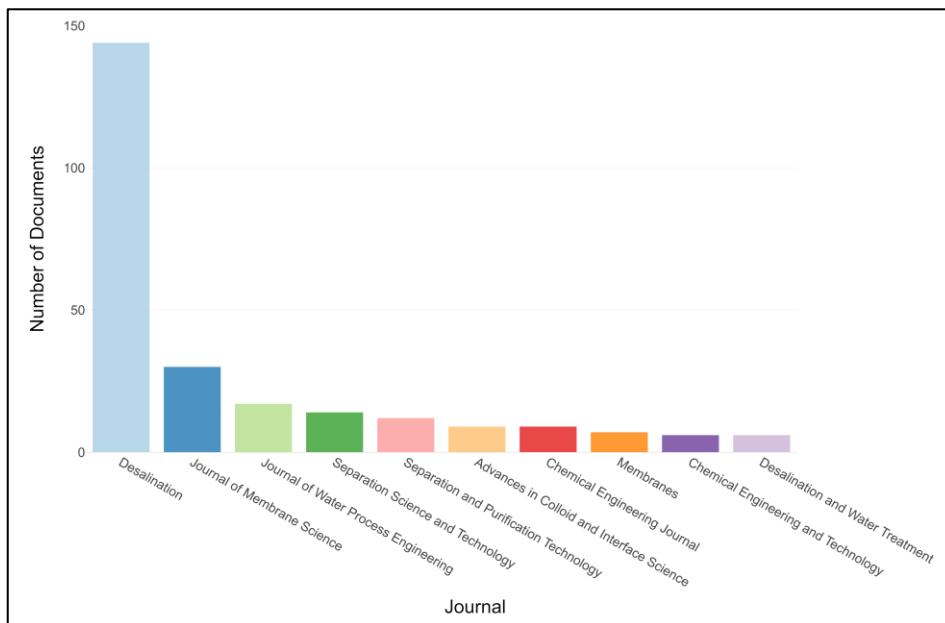


Fig. 4. Top 10 journals where Dr. Hilal publishes his studies.

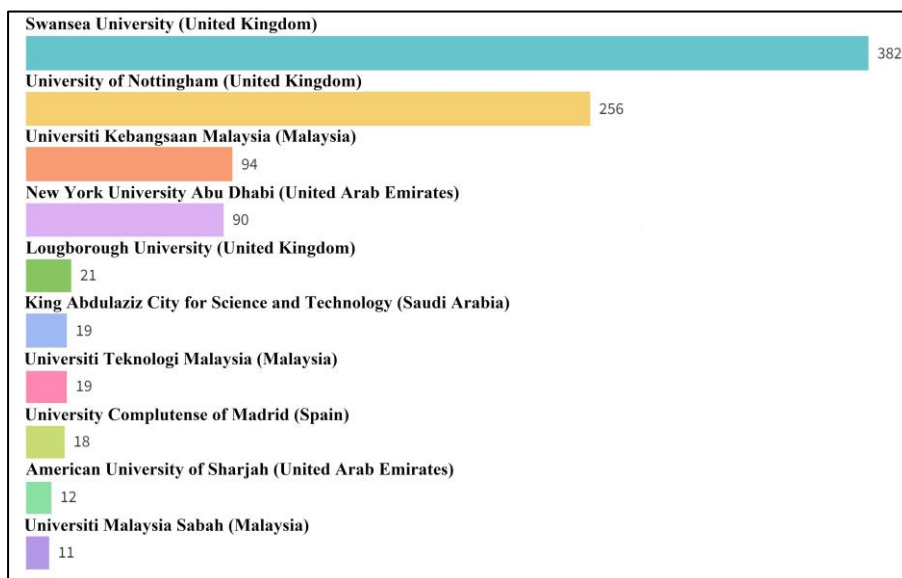


Fig. 5. Top 10 most relevant affiliations in the collected dataset.

With his good-natured and outgoing personality, Dr. Hilal has tried to disseminate scientific knowledge and be a role model for early career researchers. Being a prolific researcher has requirements such as conducting consistent and continuous research, adhering to ethical principles, generating interest in the areas of study, conducting interdisciplinary investigations, contributing to the scientific world, mentoring, and transferring scientific knowledge to the public among others. These are some of the guidelines followed by him as most of the collaborators from all around the world, some of them indicated in Fig. 6, can attest. This figure shows that Dr. Hilal has co-authored at least 10 documents with 25 scientists from all over the world. Among them, Johnson D. J. and Mohammad A. W. are his most frequent co-authors. The other researchers most repeatedly cited in collaborations with him are Kochkodan V., Darwish N. A., Ang W. L., and Khayet M.

The output of works generated by an author over time is referred to as "author production". This can include the number of books, articles, and other written works created by an author, as well as the frequency and consistency with which these are produced. Examining the author's production over time graph in a researcher's domain helps to find the people who have worked with

that scientist the longest. Related to Fig. 6, Fig. 7 shows the top 10 researchers who have published the most with Dr. Hilal.

As can be seen in Fig. 7, Mohammad A.W. is the longest-time co-author of Dr. Hilal's publications for 26 years, from 1997 to 2022. His second longest collaborator is Wright C.J., from 1998 to 2019. In the 3<sup>rd</sup> place, we can find Darwish N.A., with whom he published joint articles for 19 years, between 2003 and 2021. Fig. 7 also reveals the years during which Dr. Hilal published the most articles and received the most citations per year. The years 2015, 2019, 2017, and 2009 appear as his most productive years with 35, 29, 29, and 29 documents, respectively. Similarly, the years his publications received the highest total citations per year are 2015 (450.33), 2019 (364.20), and 2020 (246.75).

As is known, it is essential for the scientific progress of a given topic to form a collaborative network. Collaboration with research groups from other institutions is enriching as it promotes interdisciplinary research with exchange of knowledge providing access to specialized equipment/facilities and international funds. Based on the affiliations associated with publications, the collaboration network of Dr. Hilal is illustrated in Fig. 8.

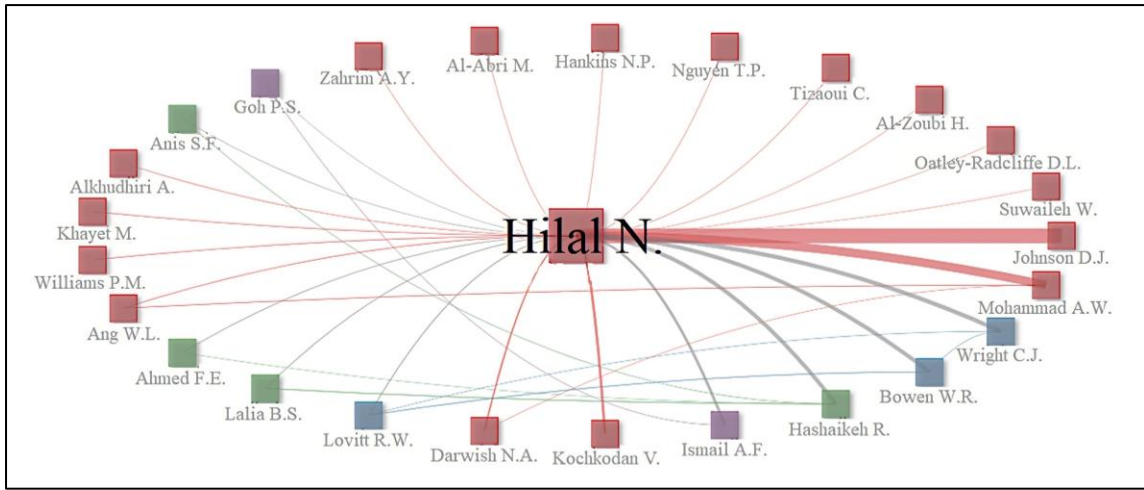


Fig. 6. Collaboration network of Dr. Hilal (min. number of edges = 10).

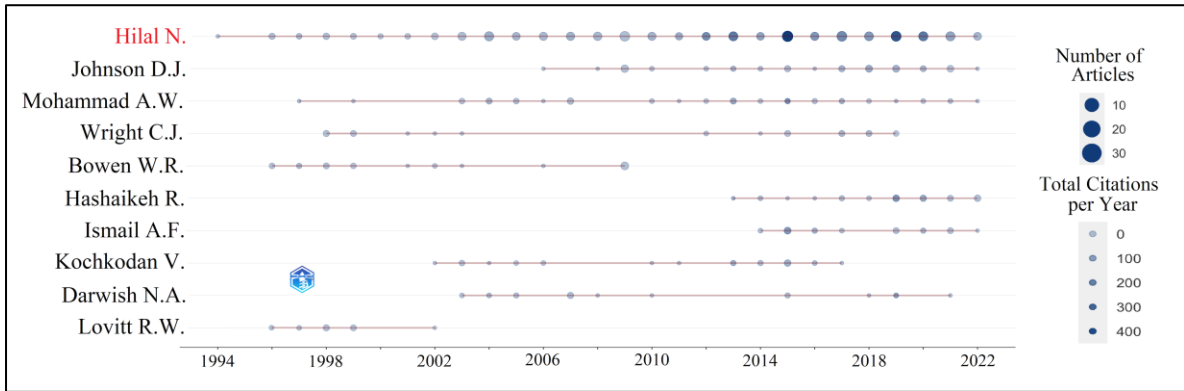


Fig. 7. Top 10 authors who published the most overtime with Dr. Hilal.

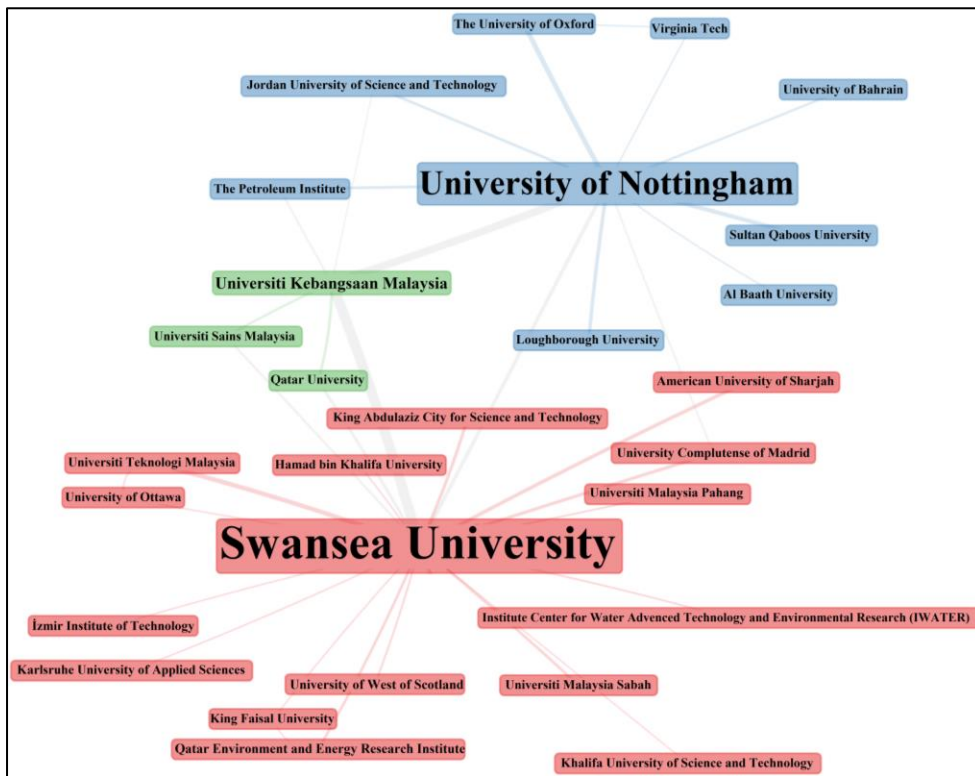


Fig. 8. Worldwide collaboration network of Dr. Hilal (min. number of edges = 3).

Fig. 8 indicates three different clusters. The largest cluster (pink cluster), with 16 universities/ research centers, is centered on Swansea University. This indicates that Dr. Hilal had more research collaborations while working at Swansea University. He cooperated more with Universiti Kebangsaan Malaysia, which is the lead institution of the small green cluster. The blue cluster formed by 9 institutions is the second largest cluster, centered on the University of Nottingham. Dr. Hilal has published at least three joint publications with 11 institutions when he was at the University of Nottingham. Interestingly, Universiti Kebangsaan Malaysia is again the affiliation with which Dr. Hilal had the most partnerships when he was at the University of Nottingham. The countries with which Dr. Hilal has collaborated are shown in Fig. 9.

Dr. Hilal worked for many years at two UK universities, Swansea University, and the University of Nottingham. In total, there are 21 countries with which he collaborated. However, 17 of them are separated in a red cluster because these countries maintained more collaborative networks. The top 5 countries are the United Arab Emirates, Malaysia, Qatar, Saudi Arabia, and Spain. In Qatar, he served as Chief Scientist at Water Security Challenge and as Senior Research Director at Environment and Water Sciences and

Technology from 2014 to 2015. Furthermore, it is clear from the country connection routes that the scientific studies conducted under the direction of Dr. Hilal resulted also in further cooperation between countries such as Malaysia and Canada, the USA and Qatar, Malaysia, and Saudi Arabia, etc. not just between the UK and these countries.

The most well-liked or often discussed subjects in a certain collection are referred to as "trending topics" based on the keywords of the published documents, the topics that Dr. Hilal emphasized more each year forming the core of his investigation are presented in Fig. 10.

Fig. 10 shows that Dr. Hilal has been interested in a wide range of topics throughout his academic career. He has conducted research on a broad spectrum of subjects. In 1996, he started his scientific studies by focusing on the "pore size distribution" of membranes and continued with topics such as "atomic force microscopy", "surface roughness", "permeate flux", "coagulation", and "membrane fouling". In 2022, the last year of the collected dataset, "nanomaterials" is his trending topic. Throughout his career, "Membranes" is the topic he focused on for the longest time (a trending topic between 2007 and 2019), while the author keyword he used the most is desalination (2017).

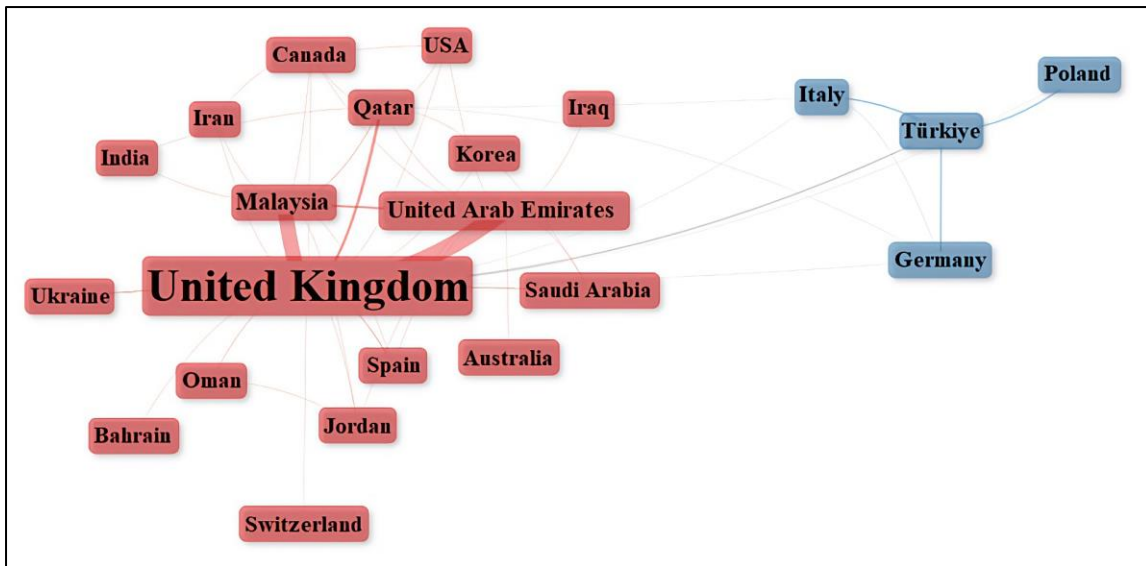


Fig. 9. Countries with which Dr. Hilal has collaborated (min. number of edges = 2).

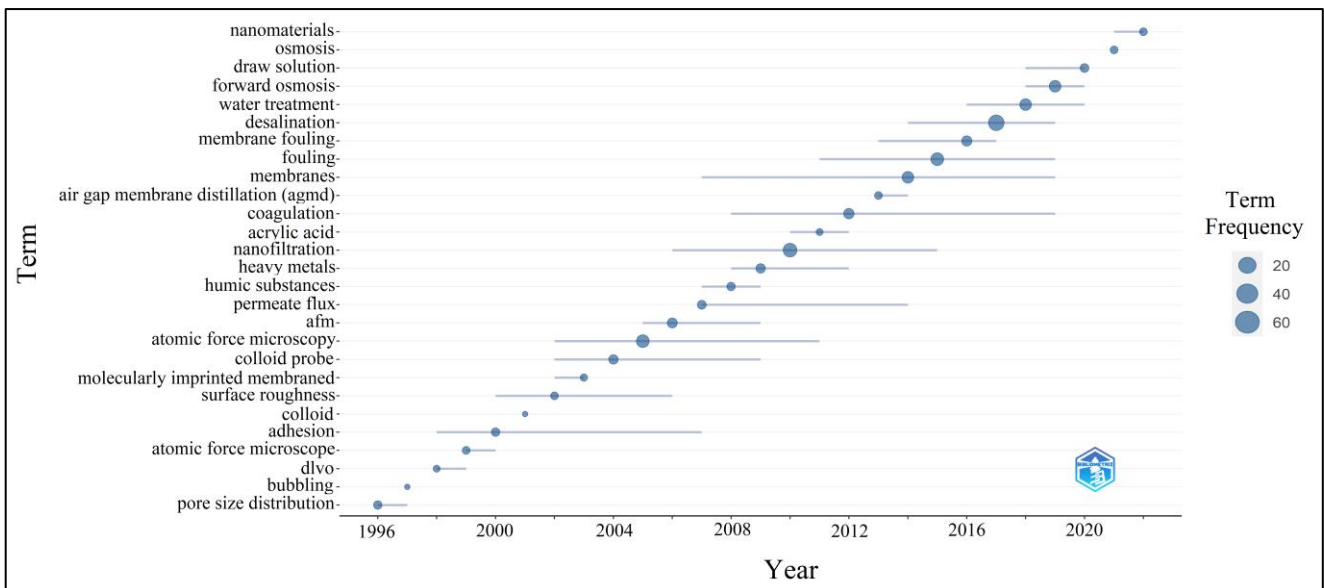


Fig. 10. Trending topics of Dr. Hilal based on the mentioned keywords in the publications.



The word cloud method aids in quickly grasping the general content or context of a document or collection of texts as well as identifying the most crucial themes within it. Here we performed word cloud analysis from the abstracts of the collected documents in the dataset. The results are illustrated in Dr. Hilal's portrait (Fig. 11).

Membrane is the research topic that marked the scientific career of Dr. Hilal performing significant and cutting-edge contributions. In fact, it is the most dominant word in all his publications (1746 times). He is also aware of the importance of fresh water for life thus he has also been devoted to the use of membranes for water treatment and desalination. Words such as surface, fouling, and flux reveal the necessary improvements to be made in membrane engineering research to reduce membrane fouling and increase the permeate flux. Mathematical or computer models for process optimization indicate that his research studies are not only limited to lab-scale research. Improving the performance of systems to produce drinking water is one of his major objectives. Atomic force microscopy (AFM) is the technique that he developed the most early in his career.

The sentiments and emotional analysis of the abstracts of Dr. Hilal's papers are illustrated in Figs. 12 and 13, respectively.



Fig. 11. Word cloud of abstracts of documents overlaid on Dr. Hilal's portrait.

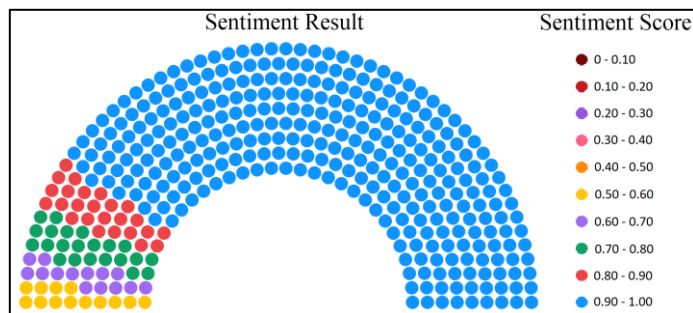


Fig. 12. Sentiment analysis result of the abstracts of Dr. Hilal's publications.

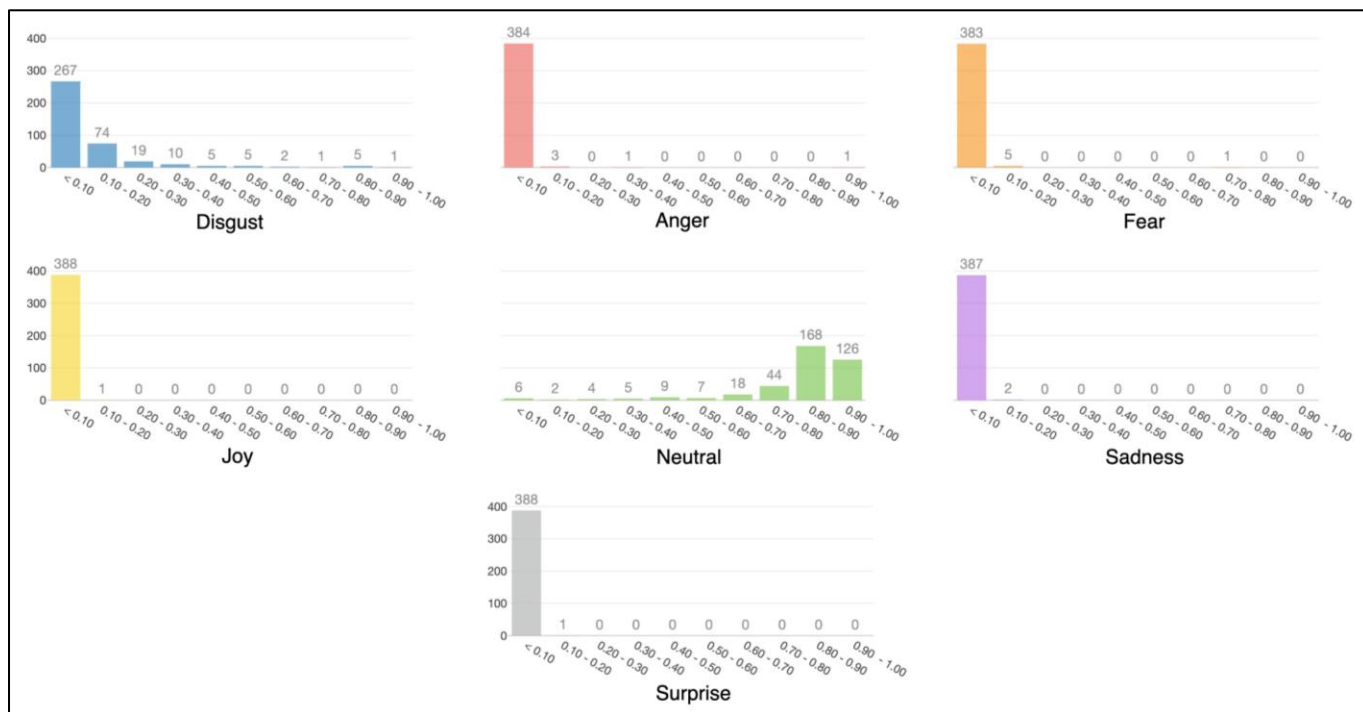


Fig. 13. Emotion analysis result of the abstracts of Dr. Hilal's publications.



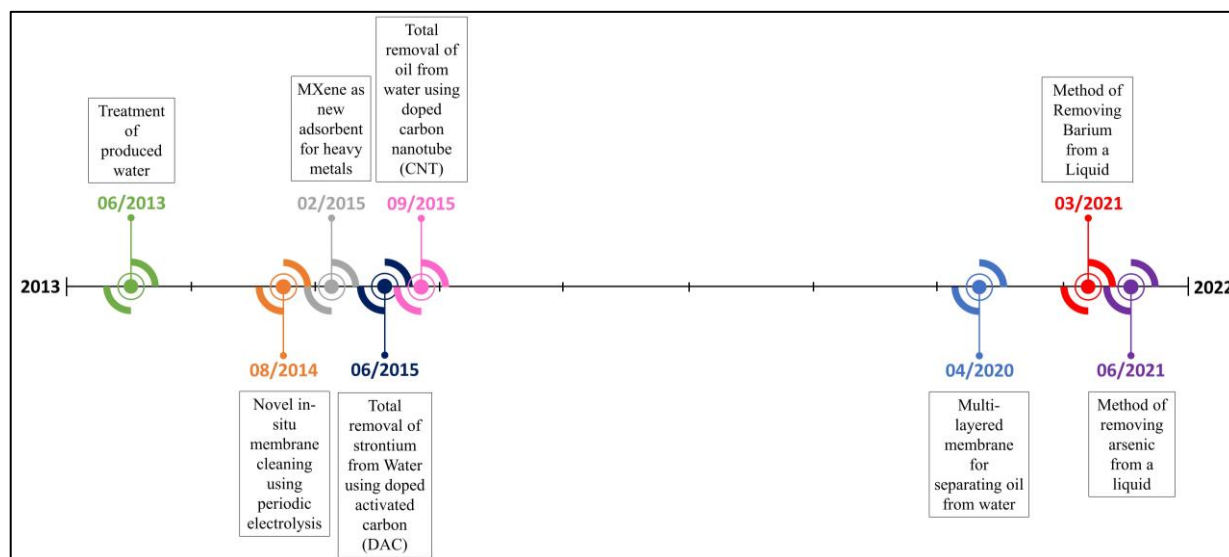


Fig. 14. Timeline of Dr. Hilal's patents.

#### 4. Conclusions

Dr. Nidal Hilal, on the cusp of his 30<sup>th</sup> year in the scientific community, is a well-known and influential scientist in the fields of membrane science, nanotechnology, and water treatment. His contribution to these research fields has been proven by numerous articles, books, book chapters, patents, and conference papers. He has earned the respect of all who have the chance to work closely with him not only in research but also in management. He has been able to forge strong collaboration networks of research groups from numerous countries. This article is a combination of statistics, bibliometrics, and machine learning to provide an in-depth insight into his scientific accomplishments. The findings of this study illustrate the substantial impact of his works on the international research community dedicated to science and technology. The results confirmed through analysis and figures that Dr. Hilal is one of the leading experts in the above-mentioned fields. We would like to express our gratitude to him for carrying the torch of science and development for so long and for illuminating with his knowledge and long experience the path of young scientists in the fields of membrane science, desalination, and related technologies. He certainly deserves a proper tribute, and the scientific community is indebted to him for all his fantastic and non-stop dedication to the development of science and technology. THANK YOU Dr. NIDAL HILAL.

#### Data availability

Data will be made available on request.

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#### CRedit authorship contribution statement

*M. Khayet*: Conceptualization; Data curation; Formal analysis; Methodology; Supervision; Validation; Roles/Writing – original draft; Writing- review & editing.

*E. Aytac*: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Resources; Software; Validation; Visualization; Roles/Writing – original draft.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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