Arabian Journal of Geosciences (2021) 14: 1950
https://doi.org/10.1007/s12517-021-08353-z

ORIGINAL PAPER

Sustainable water planning and management research in Saudi Arabia: a data-driven bibliometric analysis

Abdulaziz I. Almulhim[1] · Mohammad Aqil[2] · Shakil Ahmad[2] · Isam Mohammed Abdel-Magid[3]

Received: 31 May 2021 / Accepted: 26 August 2021 / Published online: 5 September 2021

Abstract

The present study aims to portray the Saudi scientific literature on "Water Planning and Management (WPM)" based on the bibliometric method. The Web of Science of Clarivate Analytics is used as a data source. MS Excel, VOS viewer, Biblioshiny, and BibExcel software packages are employed for data analysis and bibliometric indicator characterization. The study addresses evaluating the overall performance of WPM scientists and investigators affiliated with the Kingdom of Saudi Arabia (KSA). The set research questions are investigated within the scope of productive countries, organizations, prolific authors, highly cited researcher, preferred source, collaboration pattern, frequently used keywords, co-occurrence citation network, publication source, etc. The study used a total of 685 document types from diverse tracks. The most preferred document type observed to be an article. The year 2020 recorded maximum research productivity; however, 2016 is the peak year for citation count. King Saud University (KSU), King Abdulaziz University (KAU), and King Abdullah University of Science and Technology (KAUST) are the leading institutions in research productivity and the highest h-index. Also, KSA, the United States of America (USA), Egypt, and Pakistan are the leaders in publications, citation, and collaboration networks. The most prolific authors in terms of publications count are observed as Sen Z., Ali I., and Elhag M. "The Arabian Journal of Geosciences," "Desalination and Water Treatment," and "Water" are the top three choices for publications among the Saudi researchers.

Keywords Water planning · Water management · Sustainability · Bibliometric · Saudi Arabia

Responsible Editor: Amjad Kallel

✉ Shakil Ahmad
shahmad@iau.edu.sa

Abdulaziz I. Almulhim
aialmulhim@iau.edu.sa

Mohammad Aqil
moaqil@iau.edu.sa

Isam Mohammed Abdel-Magid
iahmed@iau.edu.sa

[1] Department of Urban and Regional Planning, College of Architecture and Planning, Imam Abdulrahman Bin Faisal University, PO Box 1982, Dammam 31451, Saudi Arabia

[2] Deanship of Library Affairs, Imam Abdulrahman Bin Faisal University, Dammam 31451, Saudi Arabia

[3] Environmental Engineering Department, College of Engineering, Imam Abdulrahman Bin Faisal University, Dammam 31451, Saudi Arabia

Introduction

Water shortage is one of the world's most pressing issues in the twenty-first century, which affects every aspect of human life. Contrary to worldwide rising water demand, freshwater resources are declining in many parts of the world due to many factors such as population growth, environmental changes, urbanization, and irrational usage (Mohorjy and Grigg 1995; Rijsberman 2006; Mekonnen et al. 2016; Siddique et al. 2020; Necibi et al. 2021). According to an estimate, the world population is expected to grow 9.7 billion in 2050 and 11 billion by 2100. By 2025, half of the world's population will be living in water-stressed areas (United Nations, Department of Economic and Social Affairs, 2019; WHO, 2019). The per capita water resources are also likely to decrease in the Middle East due to the environmental changes and population increase. This will undoubtedly have a social and economic impact on the region (Chenoweth et al., 2011). Thus, the imbalance between population and available water resources would have an adverse socio-political and socio-economic impact on the society (Haddadin 2001). Moreover, the

United Nations (UN) classified the Middle East region, including Saudi Arabia and other Gulf Cooperation Council (GCC) nations, as water-scarce nation. Almazroui (2011) classified the Saudi climate as arid and semi-arid, with low rainfall and highly evaporative, resulting in water scarcity (Assiri and Darfaoui 2009).

The KSA is on the brink of acute water shortage due to limited water resources, an arid environment, a lack of rivers, and permanent natural water bodies. Several research studies also reported the increasing water demand due to urbanization, and population growth, which is usually met by the dwindling and depleting water supply (Al-Ibrahim 1990; Ouda 2013). However, the uncertainty associated with climate change, such as rising temperature, decreasing rainfall, reference evapotranspiration, loss of soil moisture, and increasing water demand from agricultural, domestic, and industrial sectors due to population growth and industrial development, is putting more pressure on the available water resources. A significant portion of the water demand in Saudi Arabia is fulfilled by the non-renewable groundwater sources, followed by renewable sources (surface and water), desalinated water, and treated wastewater (TWW) (Chowdhury and Al-Zahrani 2015; Tarawneh and Chowdhury 2018). Some other studies reported the increase in the annual water demand of KSA (Al-Zahrani and Baig 2011). According to Chowdhury and Al-Zahrani (2013), it was 20740 MCM in 2000 and increased to 23000 MCM in 2005, an average demand increase of 1.7% per year. Another report states an 8% (3392 MCM) increase in drinking water consumption until 2018 (Argaam, 2018). In 2019, the KSA's per capita daily water consumption stood at 263 L, expected to grow 12.3 million m^3/day by 2040 (Council 2021).

On the other hand, the existing KSA population is projected to grow 32 million by 2025 and 50 million by 2050 Drewes et al. (2012). Given the growing population, infrastructure development project, and increasing freshwater demand, KSA has taken several concrete measures to address the issues related to planning and sustainable freshwater supply. Desalination is one of the most important sources of freshwater supply, which has excellent development potential. KSA has heavily invested in the desalination water industry; also it is independent of the climatic conditions, sustainability criteria, and limited supply. The establishment of Saline Water Conversion Corporation (SWCC) in 1966 under the Ministry of Environment, Water and Agriculture (MEWA) was a milestone in this direction. As of October 2020, Kingdom had 33 desalination plants in 17 different locations run by SWCC, which fulfil approximately 69% of the freshwater supply gap. The KSA is the largest producer of the desalinated water globally, accounting for 22% of global production and 54% of GCC's total. As of 2019, 60% of the total demand of KSA is fulfilled from desalinated water. By the end of 2030, MEWA would like to extend 90% of urban water supply from desalination (Council 2021; Ministry of Environment and Water 2021).

Furthermore, some remarkable initiatives in this direction are also worthy of mentioning here, such as developing the National Water Strategy, increasing the use of treated wastewater, adopting advanced and sustainable water desalination technologies, increasing the holding capacity of a surface water dam, and public-private partnerships to develop sustainable water facilities (Ouda 2014). In compliance with Saudi vision 2030, the MEWA also initiated the "Qatrah" program in March 2019 to rationalize water usage in the Kingdom by reducing water consumption by 24% in 2020 and 43% by the end of 2030 (Media, 2021). Realizing the importance of scientific research to find sustainable solutions to water scarcity, KSA has established many water research centers and advanced research programs across the Kingdom in universities and organizations and is committed to providing research funding and support.

Literature review

A significant amount of literature is produced by the Saudi and non-Saudi researchers addressing various research problems of water and associated social, economic, and environmental issues in the Saudi, MENA, and global context. Ghaffour et al. (2013) discussed desalination costing due to the techno-economic evaluation, which affects the water cost variation, energy consumption, and cost trends of various desalination technologies. Kim et al. (2017) demonstrated the design and development of a sustainable device capable of extracting atmospheric water from the air at a low humidity level of 20% without additional energy requirement. Gupta et al. (2012) discussed and highlighted different recycling and wastewater treatment methods concerning basic principles, costs, maintenance, suitability, selection parameters, etc. Zyoud et al. (2016) measured the qualitative and quantitative aspects of pharmaceutical wastewater literature of Arab countries. They compared it with Turkey, Iran, and Israel, and Saudi Arabia tops the pharmaceutical wastewater research. Zyoud and Fuchs-Hanusch (2015) assessed the desalination research productivity of the Arab world and highlighted the leadership of KSA in desalination research. Similarly, a couple of other studies demonstrated the leading role of Saudi Arabia in scientific research, such as Zyoud and Zyoud (2020) observed Saudi Arabia on the top in climate change research among the Arab world countries.

Similarly, KSA ranks six globally in the area of forwarding osmosis in desalination and wastewater treatment (Ang et al., 2019). According to Tanaka and Ho (2011), Saudi Arabia's worldwide rank on desalination research was 18. Likewise, Bador et al. (2020) analyzed the global wastewater research output indexed in Web of Science in 2019–2020; China and

the USA were the leaders in wastewater research; however, Saudi Arabia could not find a place in the top 20.

Some research studies assessed the scientific output of the Arab world and Africa in a specific domain. Zyoud and Zyoud (2021) highlighted the development trends of Environmental Impact Assessment (EIA) literature published by the Arab world. Zyoud et al. (2014) assessed the toxicology literature produced by 13 Arab countries. Wambu and Ho (2016) conducted the bibliometric assessment of drinking water research in Africa. However, a comprehensive scientometrics analysis of the literature published on water planning and management (WPM) in Saudi Arabia is missing. Therefore, the topic has great significance, especially concerning the national water strategy and Saudi vision 2030. Such a study would also prove instrumental to policymakers and funding agencies understanding the trends and planning future research strategies. The present study will investigate the various dimensions and characteristics of the literature on WPM, published with Saudi affiliation and indexed in Web of Science. The following research questions are formulated to conduct the study:

(a) What are the publishing trends of WPM research in KSA?
(b) What are the most productive authors and organizations of WPM in KSA?
(c) What are the most prominent journals and document types of WPM in KSA?
(d) What are the highly cited authors and publications in the field of WPM in KSA?
(e) What are the authorship and collaboration patterns of WPM research in KSA?
(f) What are the current research themes/keywords in the literature on WPM?

Methodology

Research methodology focused on the usage of data retrieved from the Web of Science. The search query involved the following: TS = ("Water management" OR "water planning" OR "water resources" OR "Integrated Water" OR "Water governance" OR "Water sustainability" OR "Water socio-economic" OR "Water demand management" OR "Water footprint" OR "Water demand" OR "Water harvesting" OR "Water conservation" OR "Water pricing" OR "Water lifeline" OR "Water rights" OR "Water for peace" OR "Water reuse") AND AD = ("Saudi Arabia"). The date of data extraction is 14/02/2021. The initial search results have retrieved 711 papers. The results are further refined by an article or early access or proceedings paper or review articles in inclusion and exclusion criteria. Twelve non-peer review items such as editorial materials, meeting abstracts, notes, retracted publications, corrections, and discussion are also excluded. After the title and abstract screening of each record, 14 irrelevant documents were removed from the analysis. Six hundred and eighty-five results between 1981 and 2020, consisting of journal articles (n = 606), conference papers (n = 63), reviews (n = 54), and early access (n = 12), are finally considered in data analysis. The data's accuracy was ensured by repeating the process by one team member of the research group. Data analysis was performed using various tools and software, including MS Excel (v16.0), VOS viewer (version 1.6.16), and Biblioshiny (version 3.04), Aria and Cuccurullo (2017), and BibExcel. Figure 1 portrays a four-phase search and selection approach arranged in such a way as to include publications that could be used to perform a reliable bibliometric analysis.

Results and analysis

Table 1 portrays the holistic overview and features of the dataset considered in the analysis part.

Document type

Table 2 highlights the share of document types on WPM research by Saudi scientists. The major portion of WPM research (TP = 562) items published in "article" form with the highest citation count and h-index (TC = 9237; h-index = 47); followed by (TP = 49) publications as "review" with TC = 4009 and h-index = 26. The share of "proceeding paper" is (TP = 39) with a citation count and h-index of TC = 87 and h-index = 6, while the count of "article-proceeding paper" is (TP = 24) with TC = 262 and h-index = 10. It is interesting to note that the average citation per paper (C/P = 81.82) and average citation per cited paper (C/CP = 95.45) of "review" items are far higher than the other format like "article" (C/P = 16.44), (C/CP = 19.24); "article-proceeding paper" (C/P = 10.92), (C/CP = 11.91).

Yearly publications and citation trends

The yearly research productivity and citation structure of WPM by Saudi researchers from 1981 to 2020 is interpreted in Table 3. The research publications started to appear in 1981, and the very first decade recorded ten publications. Within the next 5 years, the publications count doubled and then shows a sudden decrease until 2000. Afterwards, steady growth has been recorded until 2011. From 2011 onwards, the publication counts are constantly increasing with a few exceptions. The highest publications (TP = 117) on WPM in KSA are recorded in 2020, followed by TP = 84 in 2017 and TP = 75 in 2019. However, the highest citation count, TC = 1897, is observed in 2016, followed by TC = 1610 in 2013 and TC =

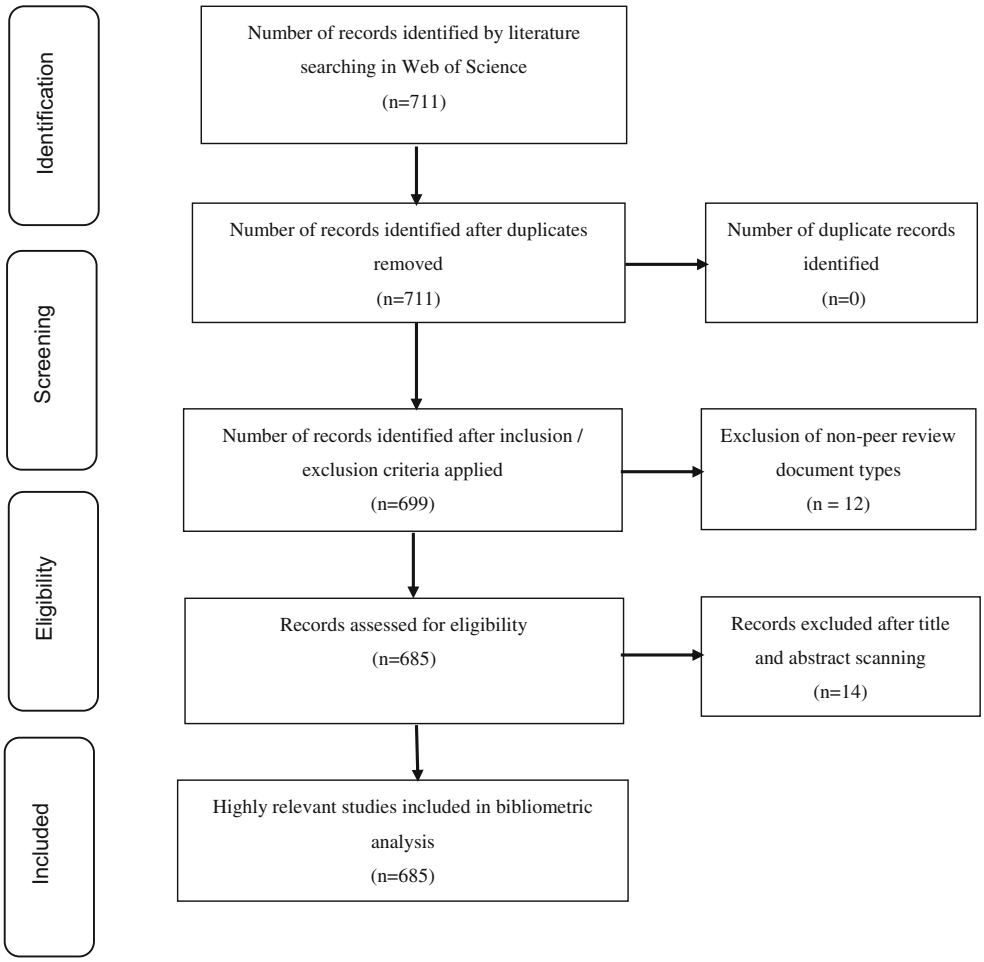


Fig. 1 Four-phased flow chart of data extraction and filtration process

1552 in 2017. Surprisingly, the highest citation per publication (C/P) is observed at 64.86, 53.85, and 42.37 in 2011, 2012, and 2013, consecutively. A score of 20 h-index appeared during the years 2015–2017. A relative value showed in 2013 (h-index = 19) with the citation (h-core) reaching its maxima (1444) in this year.

Figure 2 describes publications and citation trends in WPM from 1981 to 2020 in KSA. The increase in publications and cited publications is evident and distinct.

Table 1. Main information about data

Description	Results
Period	1981:2020
Sources (journals, books, etc.)	318
Documents	685
Authors	1932
Single-authored publications	89
Multi-authored publications	1861
Total citations received by all publications	13625
Average citations publication	19.89
Author's keywords	2176
Document types	
Article	571
Proceedings paper	63
Review	51

Country collaboration

Table 4 shows the top 10 leading countries with higher research collaboration with KSA in the WPM subject domain. The table highlights the citation count, citation impact, h-index, and the collaborating countries and continents. The analysis shows Egypt on top having the highest research collaboration (*TP* = 113) with KSA. The USA is found to be on rank 2 (*TP* = 85), followed by Pakistan (*TP* = 58), China (*TP* = 52), and India (*TP* = 44). However, the highest citation count (*TC* = 2998) is received by the USA, followed by India (*TC* = 2536) and China (*TC* = 1206). India is on the top in citation impact (*C/P* = 57.64), followed by the USA (*C/P* = 35.27). Egypt is on the bottom in terms of average citation per publication (*C/P* = 7.11). The highest collaboration is made by the Asian countries, followed by Europe and North America.

Table 2. Document-wise water management publications in Saudi Arabia 1981–2020

Document type	TP	TCP	TC	C/P	C/CP	H-index	H-core
Article	562	480	9237	16.44	19.24	47	4590
Review	49	42	4009	81.82	95.45	26	3844
Proceedings paper	39	20	87	2.23	4.35	6	65
Article-proceedings paper	24	22	262	10.92	11.91	10	212
Article-early access	9	4	9	1.00	2.25	2	7
Review-early access	2	1	24	12.00	24.00	1	24

Note: *TP*, total number of publications; *TCP*, total cited publications; *TC*, total citations; *C/P*, average citations per publication; *C/CP*, average citations per cited publication; *H-core*, citation sum within the h-core; *H-index*, author level metric of productivity and citations; *NTC*, normalized total citation

Collaborating organizations

Table 5 highlights the top ten leading collaborating institutions from KSA in WPM research. It is observed that King Saud University (KSU) leads the way in WPM research with 196 publications, citation count *TC* = 3448, and the highest h-index score of 28. King Abdulaziz University (KAU) is in the second position with 138 publications, *TC* = 2168, and h-index = 27; King Abdullah University of Science and Technology (KAUST) produced 77 publications with citation count = 3319 and h-index = 22. It is worthy to note that KAUST is having the highest average citation per publication (*C/P* = 43.10), King Abdulaziz City for Science & Technology (KACST) (*C/P* = 35.41), and King Fahd University of Petroleum and Minerals (KFUPM) (*C/P* = 34.74). The Riyadh region has contributed the highest number of publications, 237, followed by Mecca region, 219 publications, and Eastern region, with 77 research publications.

For abbreviations, refer to Table 2.

Table 3. Citation structure of water management in Saudi Arabia 1981–2020

Year	TP	TCP	TC	C/P	C/CP	H-index	H-core
1981–1990	10	8	34	3.40	4.25	7	33
1991–1995	20	17	123	6.15	7.24	11	115
1996–2000	11	10	151	13.73	15.10	9	149
2001–2005	24	19	317	13.21	16.68	14	305
2006–2010	22	18	403	18.32	22.39	15	399
2011	22	21	1362	61.91	64.86	13	1324
2012	27	27	1454	53.85	53.85	13	1369
2013	42	38	1610	38.33	42.37	19	1444
2014	32	31	1186	37.06	38.26	15	1038
2015	58	53	1218	21.00	22.98	20	988
2016	72	70	1897	26.35	27.10	20	1499
2017	84	74	1552	18.48	20.97	20	1152
2018	58	53	1123	19.36	21.19	15	887
2019	75	61	832	11.09	13.64	13	622
2020	117	69	333	2.85	4.83	9	193

The most prolific Saudi researchers

Table 6 lists the top 10 most influential authors on water management in KSA from 1981 to 2020. Sen, Z. of King Abdulaziz University has published the highest number (*TP* = 18) of research publications, followed by Ali, I. of Taibah University (*TP* = 16), and Elhag, M. of King Abdulaziz University (*TP* = 15), respectively. The publications count is observed wholly scattered over the years with no detected pattern.

However, a relationship between citation count, average citation, and h-index is being observed as Ali, I. of Taibah University, Ghaffour N., and Amy G., both affiliated to KAUST, have been regarded as the three most influential Saudi researchers in the WPM domain in terms of citation count, average citation per publication, and h-index.

The most preferred publication sources

Table 7 highlights the ten most influential journals that collectively published 26% of the research of total literature on WPM in Saudi Arabia during the given period. The Arabian Journal of Geosciences is found to be the most prominent journal with *TP* = 40 publications; followed by Desalination and Water Treatment with *TP* = 25 publications; Water is in the third position with *TP* = 22 publications. However, the journal "Desalination" is a highly impactful source of publications in citation count (*TC* = 1186), average citation per publication (*C/P* = 56.48) h-index = 12. Other journals with higher impact are the Journal of Cleaner Production with *TC* = 315, *C/P* = 26.25, and h-index = 8, followed by "Desalination and Water Treatment" where *TC* = 292, *C/P* = 11.68, and h-index = 7. Among the ten most prominent journals, Elsevier and Springer each published three journals.

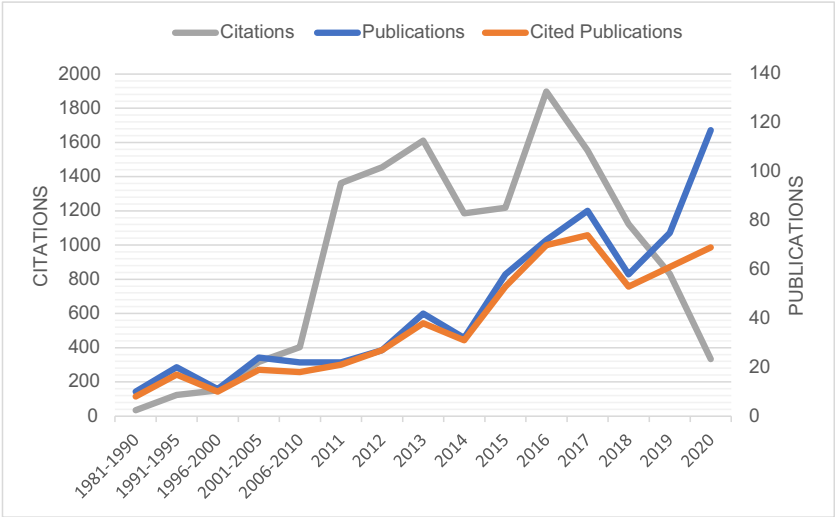


Fig. 2 Publications and citation trends in water management 1981–2020

Bibliographic coupling of source

Bibliographic coupling (BC) is a similarity measure of scientific literature. It is primarily based on the idea that the two articles that cite similar references are expected to address the related or the same research issues. Figure 3 illustrates the bibliographic coupling among selected journals. The size and color of the circles specify the BC level and coupling clusters. The journals having five or more publications are included, and 25 of 318 journals meet the criteria. The Arabian Journal of Geosciences shows the highest occurrence of the 40 documents, 215 citations, and a link strength of 485. Likewise, the journal "Desalination and Water treatment" displays the second-highest occurrence with 25 papers, 292 citations, and total link strength of 417, followed by "Journal of Membrane Science" 9 documents, 439 citations, and total link strength of 221. The most closely related journals are distributed into clusters. The clusters' connections can be described using quantitative network indicators. Bibliographic couplings of journals in Water Management and Planning literature in Saudi Arabia are distributed into the five clusters and visualized using the VOS viewer package.

Keyword analysis and hot topics

The most used authors' keywords in WPM Saudi literature are highlighted in Figure 4. The keywords up to a minimum occurrence of 8 are considered, and hence out of 2176, only 29 meet the threshold. The distance and size of the bubble indicate the occurrence of the keywords and their associational links. The top four keywords appeared more than 30 times. The keyword "Saudi Arabia" having the strongest relationship with the highest occurrence 56, followed by the "Desalination" that appears 43 times, water reuse 32, and "climate change" appears in 31 publications. VOS viewer has generated five clusters of these 29 keywords. Cluster one (red) has eight keywords, Adsorption, Desalination, Forward osmosis, modeling, Reverse osmosis, Wastewater treatment,

Table 4. Highly collaborating countries

Rank	Country	Continent	TP	TC	C/P	H-index	H-core
1	Egypt	Asia	113	803	7.11	14	468
2	USA	North America	85	2998	35.27	25	2446
3	Pakistan	Asia	58	743	12.81	15	582
4	Peoples R China	Asia	52	1206	23.19	21	1064
5	India	Asia	44	2536	57.64	18	2461
6	Australia	Australia	40	961	24.03	18	828
7	Germany	Europe	32	960	30.00	15	848
8	UK	Europe	31	869	28.03	14	833
9	Netherlands	Europe	20	651	32.55	11	622
10	Spain	Europe	20	471	23.55	11	440

For abbreviations, refer to Table 2.

Table 5. Leading collaborating organizations in KSA

Rank	Affiliation	Region	TP	TC	C/P	H-index
1	King Saud University (KSU)	Riyadh	196	3448	17.59	28
2	King Abdulaziz University (KAU)	Mecca	142	2168	15.27	27
3	King Abdullah Univ Science & Technology (KAUST)	Mecca	77	3319	43.10	22
4	King Fahd Univ of Petroleum and Minerals (KFUPM)	Eastern	61	2119	34.74	16
5	King Abdulaziz City for Science & Technology (KACST)	Riyadh	29	1027	35.41	11
6	King Khalid University (KKU)	Asir	20	62	3.10	5
7	Qassim University (QU)	Qassim	20	117	5.85	6
8	Taibah University (TU)	Madinah	18	417	23.17	9
9	Imam Abdulrahman Bin Faisal University (IAU)	Eastern	16	147	9.19	6
10	Shaqra University (SU)	Riyadh	12	23	1.92	3

Water reuse, and Water treatment. Accordingly, other clusters represented by green, blue, yellow, purple, and light blue indicate associational links (Figure 4).

Keyword's evolution

The thematic evolution of keywords during the last 40 years is illustrated in Figure 5. It shows a transformational shift, and during 2001–2019, some new research areas such as water demand, water treatment, desalination, irrigation, groundwater, and remote sensing are evolved. Some popular areas that emerged in 2019–2021 are adsorption, desalination, climate change, and GIS.

Bibliographic coupling of countries

Figure 6 illustrates the bibliographic coupling of countries published in water management in Saudi Arabia with the minimum threshold of 5 documents of a country. Of the 74 countries, 30 meet the threshold. The publication count is considered and distributed in eight clusters in the countries with the highest link strength. The figure suggests the frequent coupling among Saudi Arabia, Egypt, the USA, Pakistan, China, and India.

Bibliographic coupling of institutions

Figure 7 portrays a bibliographic network of the most influential intuitions publishing on water management in Saudi Arabia. Among the most dominant Saudi institutions in coupling are King Saud University, King Abdulaziz University, and King Abdullah University of Science and Technology. However, the prominent foreign institutions in coupling are Jamia Millia Islamia, Texas A&M University, Delft University of Technology, and Mansoura University.

Table 6 The top 10 Saudi researchers of WPM in Saudi Arabia

Rank	Author	Affiliation	Country	TP	TCP	TC	C/P	C/CP	H-index	H-core	Initial year
1	Sen Z	King Abdulaziz University	Saudi Arabia	18	16	193	10.72	12.06	8	160	1992
2	Ali I	Taibah University	Saudi Arabia	16	15	2078	129.88	138.53	12	2059	2012
3	Elhag M	King Abdulaziz University	Saudi Arabia	15	14	164	10.93	11.71	9	152	2013
4	Alazba AA	King Saud University	Saudi Arabia	13	12	330	25.38	27.50	7	749	2013
5	Amy G	KAUST	Saudi Arabia	13	13	760	58.46	58.46	11	976	2010
6	Ghaffour N	KAUST	Saudi Arabia	13	12	980	75.38	81.67	10	394	2010
7	Mccabe MF	KAUST	Saudi Arabia	13	12	401	30.85	33.42	9	311	2014
8	Abderrahman WA	King Abdulaziz University	Saudi Arabia	12	10	91	7.58	9.10	5	238	1992
9	El-Halwagi MM	KFUPM	Saudi Arabia	12	12	251	20.92	20.92	10	76	2013
10	Ghumman AR	Qassim University	Saudi Arabia	12	10	79	6.58	7.90	5	68	2011

For abbreviations, refer to Table 2.

Table 7 Most influential journals on water management in Saudi Arabia

Journal name	Publisher	Country	TP	TCP	TC	H-index	C/P	C/CP	Initial year	H-core
Arabian Journal of Geosciences	Springer	Germany	40	32	215	7	5.38	6.72	2012	123
Desalination and Water Treatment	Desalination Publications	USA	25	19	292	7	11.68	15.37	2011	254
Water	MDPI	Switzerland	22	15	157	7	7.14	10.47	2014	136
Desalination	Elsevier	Netherlands	21	21	1186	12	56.48	56.48	1981	1144
Arabian Journal for Science and Engineering	Springer	Germany	13	8	77	3	5.92	9.63	1986	262
Water Resources Management	Springer	Netherlands	13	13	267	10	20.54	20.54	2004	68
Journal of Cleaner Production	Elsevier	Netherlands	12	12	315	8	26.25	26.25	2013	303
Sustainability	MDPI	Switzerland	12	5	39	3	3.25	7.80	2016	35
International Journal of Water Resources Development	Routledge	UK	11	11	111	6	10.09	10.09	2001	93
Science of the Total Environment	Elsevier	Netherlands	10	10	260	6	26.00	26.00	2012	247

For abbreviations, refer to Table 2.

Authorship pattern

The data analysis shows that the collaborative authorship pattern is prevalent in WPM research in Saudi Arabia as 87% (n = 596 of 685) of research papers resulted from collaborative research. The highest numbers of papers (n = 119; 17.37%) are produced by three authorships with citation score TC = 2885, followed by two authors (n = 115, 16.79%), fours authors (n = 107, 15.62%), and five authors (n = 90, 13.14%) with second-highest citation score TC = 2729. Only 89 (13%) research is contributed by single authorship (Fig. 8).

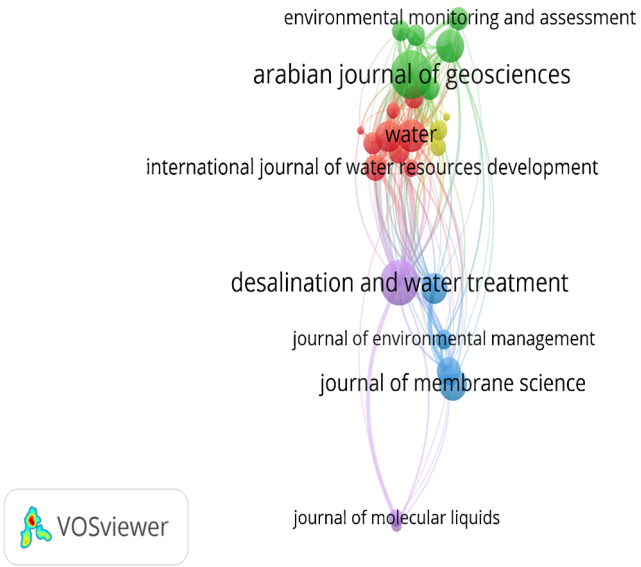


Fig. 3 Bibliographic coupling of journals with a citation threshold of 5 and 14 citations

Highly cited articles

Table 8 exhibits the bibliographic information of the top ten highly cited articles on water planning and management. The highest citation score of an article on WPM by Saudi researchers is 952, and a minimum of 150, published between the years 2011 and 2018. The research themes of highly cited articles have focused on a wide range of topics such as water recycling, water desalination, water harvesting, climate change impact, removal of pollutants by nanomaterials, water, energy sustainability, and removal of arsenic. The article "Chemical Treatment Technologies for Waste-Water Recycling-An Overview" by Gupta, V. K. published in "RSC Advances" journal the highest citation count (n = 952) and an average score of 95.20 citations per year, followed by the article "Technical Review and Evaluation of the Economics of Water Desalination: Current and Future

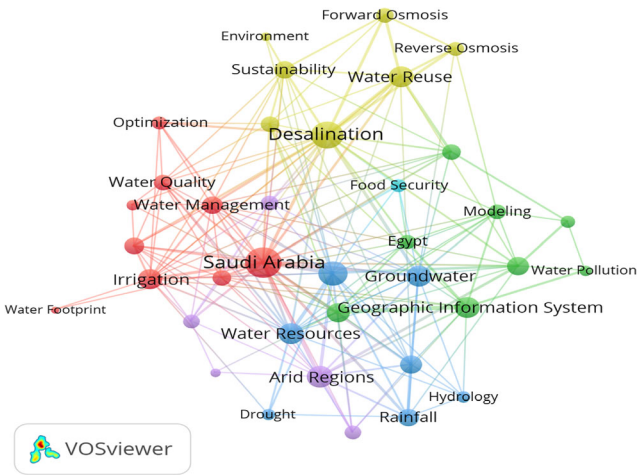


Fig. 4 Keyword's co-occurrences of 29 with a threshold of 8 occurrences

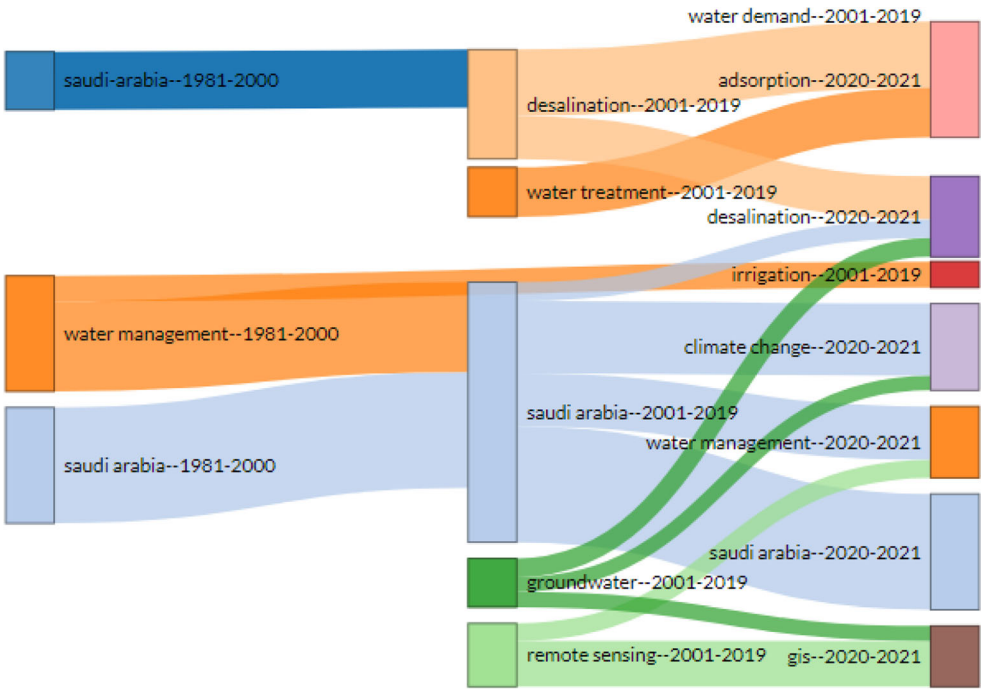


Fig. 5 Thematic map of keywords evolution (the years 1981–2000, 2001–2020)

Challenges for Better Water Supply Sustainability" by Ghaffour N. published in "Desalination" journal in 2013 with citation score *TC* = 691, and *CPY* = 76.78. However, the greatest normalized total citations (*NTC* = 25.22) were recorded for the article under the title "Water Harvesting from Air with Metal-Organic Frameworks Powered by Natural Sunlight" by Kim, H. published in "Science" journal during the year 2017.

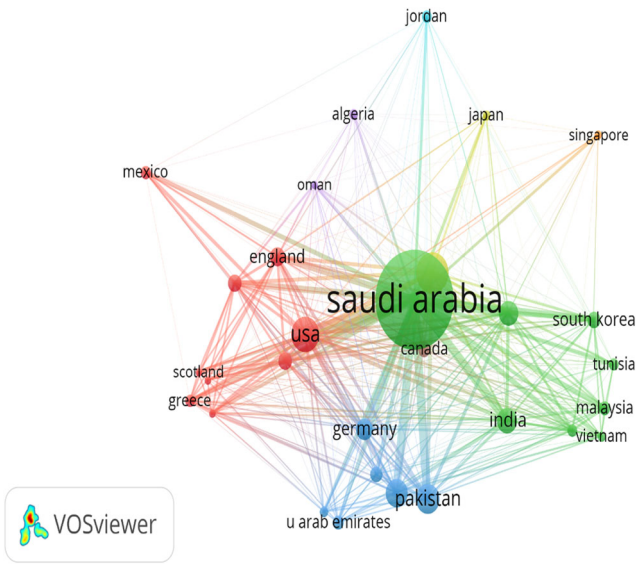


Fig. 6 Bibliographic coupling of countries published in water management in Saudi Arabia with the threshold of 5 documents 54 citations.

Country collaboration map

Figure 9 illustrates the world collaboration map on WPM in KSA. The map shows the top 20 collaborating countries; Egypt is having the highest number of collaborations (n = 113) with Saudi researchers, followed by the USA (n = 83), Pakistan (n = 57), China (n = 55), and India (n = 44). Overall, KSA is having extensive research collaboration with scientists worldwide on water planning and management.

Discussions

Saudi scientists' research productivity on water planning and management (WPM) was dispersed through various research documents and domains. Most WPM scientific writings are written in "articles," followed by "review," "proceeding paper," and "article-proceeding paper." This would reflect the authors' preference and inclination. The average citation per paper and average citation per cited paper for "review" articles are much higher than for other formats such as "article" and "article-proceeding paper." Such a trend may be attributed to institutional policy related to the promotion or other influential factors. This finding agrees with Alhibshi et al. (2020) on bibliometric analysis of neurosciences research productivity in Saudi Arabia. A similar conclusion has been pointed out by Butt et al. (2020) and Cadore et al. (2020). Likewise, Rashid et al. (2021) reached a similar conclusion while working on scientometrics analysis of 43 years of research in social support in education.

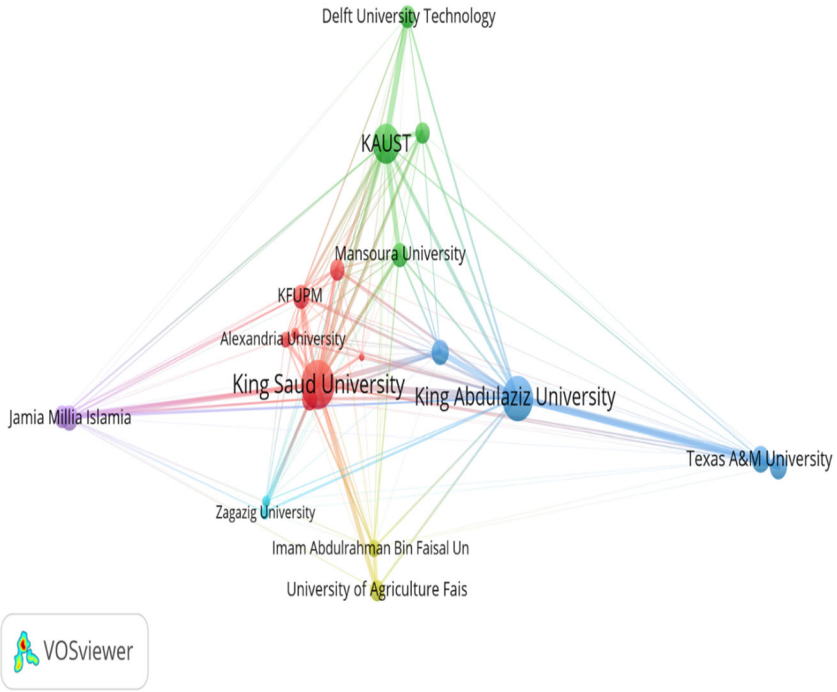


Fig. 7 Bibliographic coupling of the most influential intuitions publishing on water management in Saudi Arabia.

The rise in publications and cited publications is visible and distinct in WPM from 1981 to 2020 in KSA. The yearly research productivity and citation structure revealed that research publications began to appear in 1981. In the first decade, she recorded ten publications, followed by a 5-year rise in publications and a sudden decline until 2000. Following that, the growth is steady until 2011. The number of publications has been steadily growing since 2011, with a few exceptions. The year 2020 has the most WPM publications in Saudi Arabia. In 2011, 2012, and 2013, the highest number of citations per publication was reported. Higher education institutional development, emerging ranking patterns, accreditation, qualification pursuits, recruitment of high-quality staff, participation of more nationals in research platforms, and the launch of KSA Vision 2030 are significant factors attributed to growth in research productivity.

Fig. 8 Authorship pattern of water management in Saudi Arabia publications

The leading countries with higher research collaboration with KSA in the WPM subject domain were Egypt, the USA, Pakistan, and India. The USA, India, and China, on the other hand, earn the most citations. In terms of average citations per publication, Egypt ranks last. Asia has the highest level of cooperation, followed by Europe and North America. King Saud University, King Abdulaziz University, and King Abdullah University of Science and Technology were the top collaborating institutions from Saudi Arabia in WPM research. Industrial contacts, relationships and ties with related water departments and authorities, fund-raising patterns, outreach research joint ventures, and experience gained over time may reflect their fame.

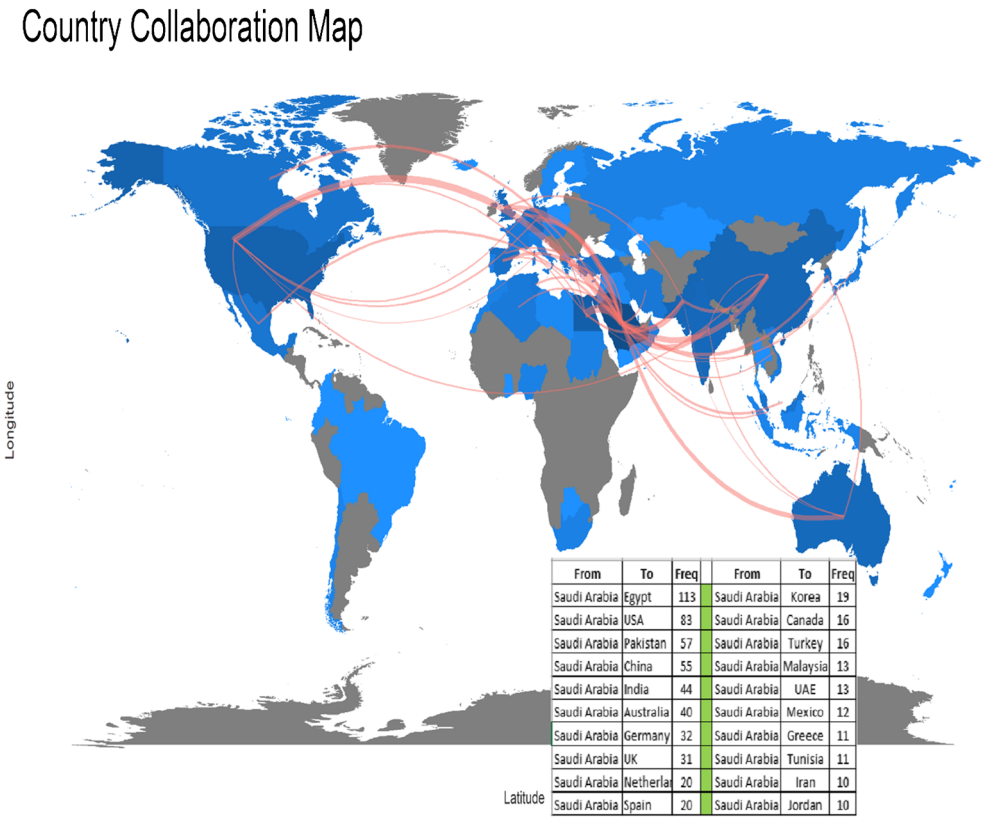
Sen, Z. of King Abdulaziz University, Ali, I. of Taibah University, and Elhag, M. of King Abdulaziz University were the topmost prominent writers on water resources in Saudi Arabia from 1981 to 2020. The publications count is observed wholly scattered over the years with no detected pattern. In terms of citation count, average citation per publication, and h-index, Ali, I. of Taibah University, Ghaffour N. of KAUST, and Amy G. of KAUST have been identified the three most prominent Saudi researchers in WPM domain.

The Arabian Journal of Geosciences, Desalination and Water Treatment, and Water were the most prominent journals in Saudi Arabia during the study period, publishing 26% of the total literature on WPM. However, in terms of citation count and average citation per article, and h-index,

Table 8 The ten most frequently cited articles were published between 1981 and 2020.

Rank	TC	Title	Author	Journal	Year	CPY	NTC
1	952	Chemical Treatment Technologies for Waste-Water Recycling-An Overview	Gupta VK	RSC Advances	2012	95.20	17.68
2	691	Technical Review and Evaluation of the Economics of Water Desalination: Current and Future Challenges for Better Water Supply Sustainability	Ghaffour N	Desalination	2013	76.78	18.03
3	466	Water Harvesting from Air with Metal-Organic Frameworks Powered by Natural Sunlight	Kim H	Science	2017	93.20	25.22
4	382	Nanostructured Materials for Water Desalination	Humplik T	Nanotechnology	2011	34.73	6.17
5	342	Impact of Climate Change on the Water Resources of the Eastern Mediterranean and the Middle East Region: Modeled 21St Century Changes and Implications	Chenoweth J	Water Resources Research	2011	31.09	5.52
6	228	A Review of Removal of Pollutants from Water/Wastewater using Different Types of Nanomaterials	Amin MT	Advances in Materials Science and Engineering	2014	28.50	6.15
7	171	Indirect Desalination of Red Sea Water with forwarding Osmosis and Low-Pressure Reverse Osmosis for Water Reuse	Yangali-Quintanilla V	Desalination	2011	15.55	2.76
8	164	Materials and Membrane Technologies for Water and Energy Sustainability	Le NL	Sustainable Materials and Technologies	2016	27.33	6.22
9	157	Metal-Organic Frameworks for Water Harvesting from Air	Kalmutzki MJ	Advanced Materials	2018	39.25	8.11
10	150	Removal of Arsenic Species from Water by Batch and Column Operations on Bagasse Fly Ash	Ali I	Environmental Science and Pollution Research	2014	18.75	4.05

For abbreviations, refer to Table 2.



From	To	Freq	From	To	Freq
Saudi Arabia	Egypt	113	Saudi Arabia	Korea	19
Saudi Arabia	USA	83	Saudi Arabia	Canada	16
Saudi Arabia	Pakistan	57	Saudi Arabia	Turkey	16
Saudi Arabia	China	55	Saudi Arabia	Malaysia	13
Saudi Arabia	India	44	Saudi Arabia	UAE	13
Saudi Arabia	Australia	40	Saudi Arabia	Mexico	12
Saudi Arabia	Germany	32	Saudi Arabia	Greece	11
Saudi Arabia	UK	31	Saudi Arabia	Tunisia	11
Saudi Arabia	Netherla	20	Saudi Arabia	Iran	10
Saudi Arabia	Spain	20	Saudi Arabia	Jordan	10

Fig. 9 Country collaboration map (top 20 countries)

the journal "Desalination" is a highly influential source of publications. The Journal of Cleaner Production and "Desalination and Water Treatment" are two other journals with a more substantial influence. Elsevier and Springer both published three journals among the ten most prestigious journals. The Arabian Journal of Geosciences had the highest occurrence of the document and relation weight about the bibliographic coupling among selected journals, followed by "Desalination and Water Treatment" and "Journal of Membrane Science." The most closely linked journals are grouped in clusters, which can be represented using quantitative network indicators. The VOS viewer software was used to analyze the bibliographic couplings of journals in Saudi Arabian Water Management and Planning literature, divided into five clusters.

The top authors' keywords in Saudi WPM literature are "Saudi Arabia," "Desalination," water reuse, and "climate change." However, the top keywords among the clusters created by the VOS viewer are Adsorption, Desalination, Forward osmosis, modeling, Reverse osmosis, Wastewater treatment, Water reuse, and Water treatment. During the last 40 years, the thematic evolution of keywords has seen a transformational change. New research areas such as water demand, water treatment, desalination, irrigation, groundwater, and remote sensing have emerged. Adsorption, desalination, climate change, and GIS are the hot topics of 2019–2021.

The bibliographic coupling of countries with the minimum threshold of 5 documents per country revealed that 30 countries met the threshold out of 74. The countries with the highest relation intensity and publication count are grouped into eight clusters, indicating that Saudi Arabia, Egypt, the USA, Pakistan, China, and India are coupled frequently. The bibliographic coupling of the most prominent Saudi institutions publishing on water resources revealed that King Saud University, King Abdulaziz University, and King Abdullah University of Science and Technology are among the most potent Saudi institutions in coupling. Jamia Millia Islamia, Texas A&M University, Delft University of Technology, and Mansoura University are prominent international institutions that show a strong relation in bibliographic coupling.

The data analysis reveals that collaborative research is prevalent in Saudi WPM literature, as evidenced by the number of research papers produced via collaborative research. Three authorships produce the maximum articles, followed by two authors, four authors, and five authors, with single authorship contributing a tiny amount of research. The importance of social support in the educational context due to an increasing trend of inclusion and diversity in the education field is highly stressed upon by Maassen (2016); Wen et al. (2017); and Rashid et al. (2021). Similar conclusions were outlined by Ul Haq et al. (2020) while measuring Saudi Arabia's health sciences research productivity.

The highly cited papers on water planning and management revealed that all articles published between 2011 and 2018 received citations ranging from 952 to 150. Highly cited papers

focus on a wide range of topics such as water conservation, water desalination, water storage, climate change effects, pollution removal by nanomaterials, water, energy sustainability, and arsenic removal. The article "Chemical Treatment Technologies for Waste-Water Recycling-An Overview" by Gupta, V. K. published in "RSC Advances" journal received the highest citation score, followed by the article "Technical Review and Evaluation of the Economics of Water Desalination: Current and Future Challenges for Better Water Supply Sustainability" by Ghaffour N. published in "Desalination" journal in 2013. However, the greatest normalized total citations recorded for the article under the title "Water Harvesting from Air with Metal-Organic Frameworks Powered by Natural Sunlight" by Kim, H. published in "Science" journal during the year 2017.

Overall, KSA has comprehensive water preparation and management research partnership with scientists all over the world. Among the top collaborating countries, Egypt has the maximum collaborations with Saudi researchers, followed by the USA, Pakistan, China, and India. For researchers and industry professionals interested in the concept and interpretation of WPM, these bibliometric findings provide a valuable guide and knowledge on current research directions. This result is consistent with that of Ang et al. (2019), who concluded their studies on research patterns in desalination and wastewater treatment over the last decade.

Conclusions

The current work reviewed the literature on water planning and management published between 1981 and 2020 using bibliometric and visualization methods. A total of 685 documents were examined from the Web of Science database during the research period. Saudi Arabia, Egypt, the United States, and Pakistan had the highest research publications, citations, and research collaboration rates. Nonetheless, when it comes to the citation impact, the United States is on the top. The highest research-producing organizations in water planning and management were King Saud University and King Abdulaziz University. In terms of publications count, the most prolific authors were Sen Z. of King Abdulaziz University, Ali I. of Taibah University, and Elhag M. of King Abdulaziz University. However, it is interesting to note that Ali I. leads the top position in total citations, citation impact, and h-index. Ghaffour N. and Amy G. are both associated with KAUST. Arabian Journal of Geosciences, having a publication scope in hydrology, hydrogeology, and hydrochemistry, is the first choice among Saudi researchers. Water recycling, water desalination, water harvesting, climate change effects, pollution reduction by nanomaterials, water, energy sustainability, and arsenic removal were among the hot research areas published between 1981 and 2020. The article titled "Chemical Treatment Technologies for Waste-Water Recycling-An Overview" by Gupta, V. K. published in RSC Advances journal acquired the highest CPY. The greatest NTC was recorded for the article under the title "Water Harvesting from Air with Metal-Organic Frameworks Powered by Natural Sunlight" by Kim, H., published in Science journal. The country collaboration and partnership map showed a significant collaboration between Saudi Arabia and Europe, America, Asia, and Australia. These relations, in particular, are thriving in terms of water management and planning.

Author contribution Yes

	Dr. Abdulaziz Almulhim	Mohammad Aqil	Shakil Ahmad	Prof. Isam Mohammed Abdel-Magid
Concepts	✓	✓		
Design	✓	✓		✓
Definition of intellectual content	✓	✓	✓	
Literature search			✓	
Clinical studies				
Experimental studies				
Data acquisition			✓	
Data analysis		✓	✓	
Statistical analysis			✓	
Manuscript preparation	✓	✓	✓	✓
Manuscript editing	✓	✓		✓
Manuscript review	✓	✓		✓
Guarantor		✓		

Availability of data and material Figshare and 10.6084/m9.figshare.14672619

Code availability NA

Declarations

Conflict of interest No.

References

Alhibshi AH, Alamoudi WA, Ul Haq I, et al. (2020) Bibliometric analysis of neurosciences research productivity in Saudi Arabia from 2013-

2018. Neurosciences (Riyadh, Saudi Arabia) 25:134–143. 10/gjwhh2
Al-Ibrahim AA (1990) Water use in Saudi Arabia: problems and policy implications. Journal of Water Resources Planning and Management 116:375–388. 10/cg88kw
Almazroui M (2011) Calibration of TRMM rainfall climatology over Saudi Arabia during 1998–2009. Atmospheric research 99:400–414. 10/cdfpzj
Al-Zahrani KH, Baig MB (2011) Water in the Kingdom of Saudi Arabia: sustainable management options. J Animal Plant Sci 21:601–604
Ang WL, Wahab Mohammad A, Johnson D, Hilal N (2019) Forward osmosis research trends in desalination and wastewater treatment: a review of research trends over the past decade. Journal of Water Process Engineering 31:100886. 10/gjtjxr
Argaam A Saudi Arabia's drinking water consumption rose 8% in 2018. In: ArgaamPlus. https://www.argaam.com/en/article/articledetail/id/1312492. Accessed 23 May 2021
Aria M, Cuccurullo C (2017) bibliometrix: an R-tool for comprehensive science mapping analysis. J Inform 11:959–975
Assiri A, Darfaoui E (2009) Response to climate change in the Kingdom of Saudi Arabia. A report prepared for FAO-RNE 17:
Bador EM, Abdel-Magid IM, Ahmad S, Akhter M (2020) Bibliometric analysis of wastewater literature published in Web of Science 2019 to 2020. Library Philosophy and Practice 1–21
Butt FM, Ashiq M, Rehman SU, et al. (2020) Bibliometric analysis of road traffic injuries research in the Gulf Cooperation Council region [version 2; peer review: 3 approved, 1 approved with reservations]. F1000 research 9:1155–1155. 10/gjwhh5
Cadore JS, Fabro LF, Maraschin TG, et al. (2020) Bibliometric approach to the perspectives and challenges of membrane separation processes to remove emerging contaminants from water. Water Science and technology 82:1721–1741. 10/gjwhh6
Chenoweth, J., Hadjinicolaou, P., Bruggeman, A., Lelieveld, J., Levin, Z., Lange, M. A., Xoplaki, E., & Hadjikakou, M. (2011). Impact of climate change on the water resources of the eastern Mediterranean and Middle East region: modeled 21st-century changes and implications. Water Resour Res, 47(6).
Chowdhury S, Al-Zahrani M (2015) Characterizing water resources and trends of sector-wise water consumptions in Saudi Arabia. Journal of King Saud University-Engineering Sciences 27:68–82. 10/gjw7h8
Chowdhury S, Al-Zahrani M (2013) Implications of climate change on water resources in Saudi Arabia. Arabian Journal for Science and Engineering 38:1959–1971. 10/f45cn7
Council U-SB (2021) Water in Saudi Arabia: desalination, wastewater, and privatization – USSBC. https://ussaudi.org/water-in-saudi-arabia-desalination-wastewater-and-privatization/. Accessed 23 May 2021
Drewes JE, Patricio Roa Garduño C, Amy GL (2012) Water reuse in the Kingdom of Saudi Arabia—status, prospects, and research needs. Water Sci Technol Water Supp 12:926–936. 10/gjw7jc
Ghaffour N, Missimer TM, Amy GL (2013) Technical review and evaluation of the economics of water desalination: current and future challenges for better water supply sustainability. Desalination 309:197–207
Gupta VK, Ali I, Saleh TA, Nayak A, Agarwal S (2012) Chemical treatment technologies for wastewater recycling—an overview. RSC Adv 2(16):6380–6388
Haddadin MJ (2001) Water scarcity impacts and potential conflicts in the MENA region. Water international 26:460–470. 10/crprqq
Kim H, Yang S, Rao SR, Narayanan S, Kapustin EA, Furukawa H, Umans AS, Yaghi OM, Wang EN (2017) Water harvesting from air with metal-organic frameworks powered by natural sunlight. Science 356(6336):430–434
Maassen S (2016) Bibliometric analysis of research on wastewater irrigation during 1991–2014. Irrigation and drainage 65:644–653. 10/f9p2nf
Media, EB (2021) Saudi Arabia launches program for a drastic reduction in water use | WaterWorld. https://www.waterworld.com/international/potable-water/article/16202937/saudi-arabia-launches-program-for-a-drastic-reduction-in-water-use. Accessed 23 May 2021
Mekonnen MM, Mekonnen MM, Hoekstra AY, Hoekstra AY (2016) Four billion people facing severe water scarcity. Science advances 2:e1500323. 10/gc6xww
Ministry of Environment and Water (2021) National water strategy. https://www.mewa.gov.sa/en/Ministry/Agencies/TheWaterAgency/Topics/Pages/Strategy.aspx. Accessed 23 May 2021
Mohorjy AM, Grigg NS (1995) Water-resources management system for Saudi Arabia. Journal of water resources planning and management 121:205–215. 10/dm6zpg
Necibi MC, Dhiba D, El Hajjaji S (2021) Contaminants of emerging concern in African wastewater effluents: occurrence, impact and removal technologies. Sustainability (Basel, Switzerland) 13:1125. 10/gjwhjk
Ouda OK (2013) Towards an assessment of Saudi Arabia public awareness of water shortage problem. Resour Environ 3:10–13
Ouda OK (2014) Water demand versus supply in Saudi Arabia: current and future challenges. International Journal of Water Resources Development 30:335–344. 10/gjw7h7
Rashid S, Rehman SU, Ashiq M, Khattak A (2021) A scientometric analysis of forty-three years of research in social support in education (1977–2020). Education sciences 11:149. 10/gjwhjn
Rijsberman FR (2006) Water scarcity: fact or fiction? Agricultural water management 80:5–22. 10/ddjgq8
Siddique N, Rehman SU, Khan MA, Altaf A (2020) Library and information science research in Pakistan: a bibliometric analysis, 1957–2018. Journal of librarianship and information science 53:89–102. 10/gh4tbf
Tanaka H, Ho Y-S (2011) Global trends and performances of desalination research. Desalination and Water Treatment 25:1–12. 10/cn8kdf
Tarawneh QY, Chowdhury S (2018) Trends of climate change in Saudi Arabia: implications on water resources. Climate 6:8. 10/gjw7jb
Ul Haq I, Rehman SU, Al-Kadri HM, Farooq RK (2020) Research productivity in the health sciences in Saudi Arabia: 2008-2017. Annals of Saudi medicine 40:147–154. 10/gjwhjp
United Nations. Department of Economic and Social Affairs. (2019). World population prospectus 2019. https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html
Wambu EW, Ho Y-S (2016) A bibliometric analysis of drinking water research in Africa. Water Sa 42:612–620. 10/gjthpk
Wen B, Horlings E, van der Zouwen M, van den Besselaar P (2017) Mapping science through bibliometric triangulation: an experimental approach applied to water research. Journal of the Association for Information Science and Technology 68:724–738. 10/f9tvd4
Zyoud S, Fuchs-Hanusch D (2015) Estimates of Arab world research productivity associated with desalination: a bibliometric analysis. IDA Journal of Desalination and Water Reuse 7:3–16. 10/gjw7h9
Zyoud SH, Al-Jabi SW, Sweileh WM, Awang R (2014) A bibliometric analysis of toxicology research productivity in Middle Eastern Arab countries during a 10-year period (2003-2012). Health Research Policy & Systems 12: 10/gjw7jf
Zyoud SH, Zyoud AH (2020) Coronavirus disease-19 in environmental fields: a bibliometric and visualization mapping analysis. Environ Dev Sustain. 23:8895–8923. https://doi.org/10.1007/s10668-020-01004-5
Zyoud SH, Zyoud AH (2021) Mapping environmental impact assessment research landscapes in the Arab world using visualization and bibliometric techniques. Environ Sci Pollut Rese:1–24
Zyoud SH, Zyoud SH, Al-Jabi SW, et al. (2016) Contribution of Arab countries to pharmaceutical wastewater literature: a bibliometric and comparative analysis of research output. Annals of occupational and environmental medicine 28:28–28. 10/gjwhjq