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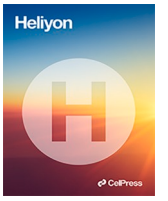

Research article

Gulf Cooperation Council countries' water and climate research to strengthen UN's SDGs 6 and 13

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ABSTRACT

Clean water and sanitation and climate actions represent two of the seventeen United Nations Sustainable Development Goals (SDGs). Although challenging, the two goals can be achieved by 2030 through unconventional and innovative solutions. Scientific research related to clean water and sanitation (SDG 6) and urgent actions to combat climate change and its impacts (SDG 13) will help develop new technologies to support the two goals and can bridge the gap between practitioners and academia's to achieve sustainability. The Gulf Cooperation Council (GCC) countries are located in an arid region. Their water and climate research activities and outcomes may provide a good contribution toward achieving the two goals. This study used text mining and bibliometric methods to analyze water and climate research contributions to achieve SDGs 6 and 13 in GCC countries. Results revealed that there is an increase in research publications after 2016 in the areas of water and climate in the GCC countries involving a longstanding international collaboration with developed countries. Research topics were focused on wastewater treatment, contamination, heavy metal, groundwater, and climate change impacts. Under SDG 6, most of the publications were research articles (77.3%), followed by reviews (11.1%), and the rest were book chapters and conference papers. For SDG 13, 75.1% of the publications are research articles, 10.9% are conference papers, and 8% are reviews. The research outcomes in the GCC countries have clearly contributed to the development of water and climate strategies and international collaborations to achieve the two goals.

1. Introduction

In the United Nations 2030 agenda, seventeen Sustainable Development Goals (SDGs) are identified to achieve the sustainable development and a better future [1,2]. Clean water and sanitation (SDG 6) and climate action (SDG 13) are two of the seventeen goals addressing availability of water and sanitation and the capacity to deal with climate change impacts [3]. In SDG 6, six targets covering the water cycle are introduced, while in SDG 13, three main targets are established for climate related hazards (Fig. 1).

The availability and quality of water are important components of economic welfare, human society, and environmental well-being. Climate change has adverse effects in some regions due to the change in the precipitation patterns, warmer surface temperature, increase in evaporation rates, and decrease in coastal and inland water quality. Some studies documented that the world is not yet on track to achieving sustainable goals [4–6]. According to a United Nations report, 23% of the world population still receive contaminated water resulting in diarrheal and hepatitis diseases spreading and causing juvenile casualties in developing countries

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[7–9]. On the other hand, hospitalization and increased mortality rates due to heat waves are also observed in different countries [9–11]. Excessive precipitation events are correlated with waterborne disease outbreaks [12–14]. Due to climate change, an increase in global temperature and flooding events has been observed in recent years [15–17]. Flooding is also linked with infections in developing countries where water resources are compromised [18,19]. Heavy rains may deteriorate surface water quality and lead to adverse health effects. It is reported that a combination of water temperature and increased nutrient concentrations may enhance the number of cyanobacterial blooms [20]. The upsurge in global diseases is strongly anticipated due to climate change. Warmer conditions enhance particular vector-borne diseases such as malaria [9,21].

Novel scientific visions and technological upgradation are instruments to overwhelm the local challenges to achieve sustainable development goals [4]. Artificial intelligence, digital technology, and automation have far-reaching impacts on the water sector and climate change tackling [4,22]. Science and technology-derived solutions are needed for securing a sustainable environment and efficient water management systems. On the other hand, capitalizing science and technology instruments for making policies and strategies to tackle climate and better management of water systems may jeopardize achieving SDGs 6 and 13. From this point of view, a systematic analysis is carried out to assess the contribution of water and climate research in support of the achievement of SDGs 6 and 13 and their targets. Considering the Gulf Cooperation Council (GCC) countries as a case study, we applied a text mining and bibliometric analysis to examine publications targeting climate and water sectors with a wide range of complementary areas including, among others, water resources management, scarcity, sanitation, private sector development, national policies, awareness, mitigation, and adaptation to climate change. The GCC is composed of United Arab Emirates (UAE), Saudi Arabia, Qatar, Oman, Kuwait, and Bahrain. The GCC countries share a similar climate and environmental conditions. The demands for water have increased significantly due to rapid increase in population, expansion in industrial and agricultural activities, improvement of living standards, and development of large green areas to improve the environmental conditions. Leakage from distribution networks and over-irrigation contributed to the groundwater problems in many cases [23]. In recent years, more emphasis has been devoted to recycling and reuse of treated wastewater to avoid the depletion of aquifers. Lakes and the perennial river are mostly absent in the GCC countries. However, some mountainous terrain does exist in Oman, UAE, and Saudi Arabia. Thus, GCC countries are mostly dependent on groundwater and non-conventional water resources [24–27]. For example, the UAE heavily relies on non-conventional water resources, including desalination and water recycling. The UAE's near-total reliance on desalination for domestic water supply has an

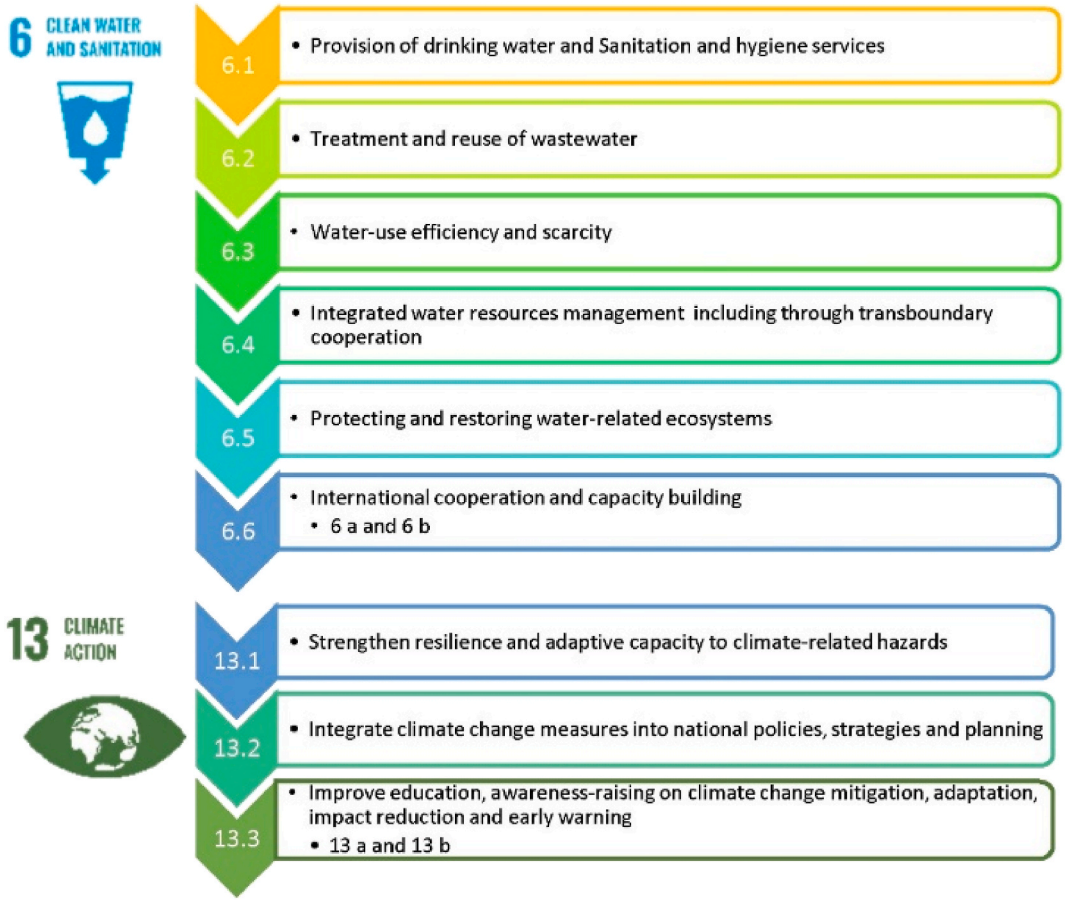

Fig. 1. Description of SDG 6 and SDG 13 targets.

inescapable impact on the environment. The GCC countries also face the same climate change challenges. For example, in UAE, climate change will likely have its most adverse impacts if there is substantial warming in the winter months, as the summers are already extremely warm and dry [28]. Hence, UAE may become an extreme water-stressed country [29–31]. Irrigation water in UAE is mostly secured from limited, nonrenewable, groundwater resources [32]. A recent study indicated that there has been an increase in temperature of up to 1.9 °C during the last 50 years [33]. Being the hottest region in the world and fulfilling its water demands by non-conventional means (mostly desalination), adverse impacts of climate change are still expected despite GCC's resilience to extreme conditions and environmental security if the global society fails to curb global temperature rise [33–36]. Thus, water and climate scenarios may challenge the GCC countries to achieve SDGs 6 and 13.

This paper assesses the scientific contributions related to water and climate sectors to support the achievement of SDGs 6 and 13. It should be noted that social sciences literature and methods for SDGs are rather limited but the technical and natural sciences are well covered in bibliographic databases.

2. Material and methods

Bibliographic data was downloaded from the Scopus database. This database contains citations and international abstracts of published literature. The publications related to water and climate (SDGs 6 and 13) were filtered. To avoid inconsistencies, SDGs 6 and 13 and target terms were also used to filter the related published material. Duplicate, redundant, too specific, and general terms were eliminated due to irrelevancy. For targets, scarcity, water resources management, wastewater, groundwater, water quality, hydrology, water modeling, precipitation, drought, climate change, mitigation, adaptation, resilience, etc., terms were chosen to extract the data. Additional keywords used for analysis are presented in supplementary material. For this purpose, *rscopus* package was used in R statistical software [37]. For searching the data, a simple search query temperate (TITLE OR AUTHORKEY OR AFFILCOUNTRY) was filled. All water and climate-related research publication data from 1926 to 2021 was sorted. For data analysis, VOSviewer software and bibliometrix package in R were used [38,39].

3. Results and discussion

3.1. Water and climate research in GCCs

In GCC countries, the first document related to water research was published in 1979 and the total number of Scopus published documents is 2970, with large number published in 2021 and 2022 (483 & 486), respectively. The majority of the publications were research articles (77.3%), followed by reviews (11.7%), and the rest were book chapters and conference papers. The number of articles dramatically increased after 2003 with most articles focused on water research (Fig. 2). Overall, 801 articles were published as open access. Saudi Arabia leads in publishing water research articles in open access. The United Arab Emirates comes second and then Qatar. In GCC countries, Saudi Arabian universities highly support open access which provides easy access to global researchers and scientists to knowledge and science for achieving sustainable goals.

Regarding SDG 13 (climate action), the number of documents (5687) is much higher than that related to water research. The first document was published in 1972 and more than 1000 documents were found in 2021. Most of the articles are research articles (75%), conference papers (11%), and reviews only 8% (Table 1).

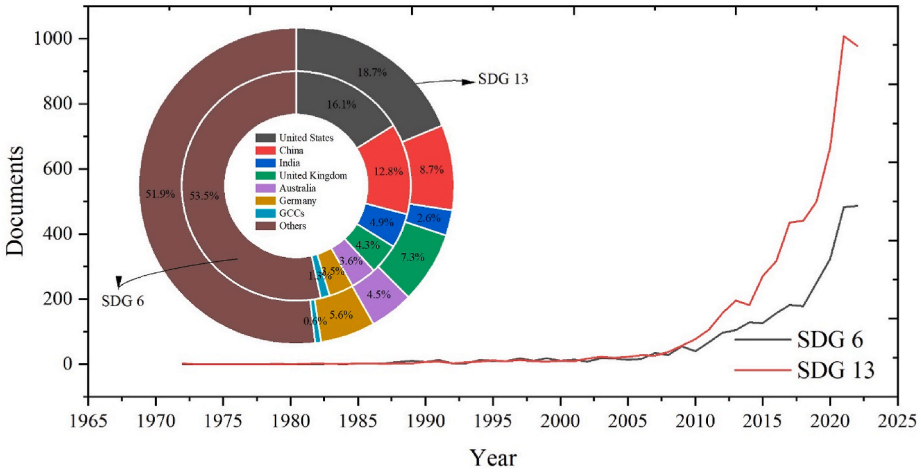

Fig. 2. Number of documents published in the water and climate domain from 1972 to 2022. The Pie chart (outer rings = SDG 13, and inner rings = SDG 6) represents the share of GCC countries in comparison to the other top 6 countries. The black and red solid lines represent the trend in publications related to SDGs 6 and 13, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
No of documents published under SDGs (6 and 13) in GCC countries.

Documents	SDG 6	SDG 13
Article	2295	4265
Review	348	450
Conference Paper	190	625
Book Chapter	121	250
Book, Editorial and other documents	16	97
	2970	**5687**

In comparison to other countries such as the United States and China, the share of documents published in SDGs 6 and 13 is 1.3% and 0.6%, respectively. In 2020 and 2021 there was a rapid increase in the water and climate research domain in the GCC countries. Researchers mostly focused on water treatment, desalination, groundwater, aquifers, carbon, carbon emissions, climate models, and pollution which showed a diversified research pattern in GCC countries. Most of the papers were published in the science of the total environment, journal of cleaner production, desalination, and water research. Most of the published research on water and climate actions exhibited that there is a need to act against changing climate and to protect water resources for sustainable livelihood. In GCC countries, a swift boost in water and climate research has been witnessed in recent years, with more than 400 publications in 2021. Although it is an arid region and there is no river except for some mountainous areas, GCC countries' contribution to achieving SDGs 6 and 13 is still significant relative to other countries. To achieve these results, a heavy investment in research programs at different institutes and universities of GCC countries has been implemented.

3.2. International research collaboration

Many indicators can be used to reflect research progress such as counts of scientific publications, patents, citations, and their impact on the economy and society. Researchers from the GCC region have coauthored papers with other regional and international researchers indicating their vast international collaboration network concerning SDGs 6 and 13. The top collaborators with GCC countries are presented in Fig. 3. The research collaboration seems to be geographically diverse. The United States, China, India, and Australia (Fig. 3) are top water and climate research collaborators with GCC countries. The collaborating countries are most valuable in producing scientific research around the globe. But the gap with European counties is more in collaboration and from the top 5 countries, only Spain and Sweden have collaborated with Oman and Bahrain.

Recently, a concrete proposal was presented to form a joint communication between European countries and GCC countries to strengthen cooperation on climate change, green transition, and other important issues including diversification for global security and regional stability. This cooperation will be mutually beneficial because climate change impacted the GCC and European regions. They were also the first to take the initiative to collaborate to overcome the challenges related to SDGs 6 and 13.

Within GCC countries, it is noted that Saudi Arabia, UAE, and Qatar have a noticeable growth in academic research related to SDGs. Saudi Arabia has performed the most notable research on water and climate and remains first among the GCC countries. UAE is ranked second in targeting SDGs. Qatar is also producing a reasonable number of related publications. Less numbers of water and climate change publications are produced by researchers Oman, Kuwait, and Bahrain (Fig. 4). In 2021, Saudi Arabia produced more than 900 research papers followed by UAE (280), Qatar (146), and Oman, Kuwait, and Bahrain collectively produced under 100. Considering the population, Qatar has a high number of per capita publications related to SDGs 6 and 13. The analysis of recent years related to publications revealed that Saudi Arabia has a higher focus compared to other countries on climate action than water and sanitation research. The number of publications on climate action exceeded 2500, while for water and sanitation the number is less than 2000. Saudi Arabia has good collaboration with neighboring and international countries to strengthen SDGs 6 and 13.

3.3. Research hotspots

Water and climate research hotspots in relation to SDGs 6 and 13 were identified by the clusters' analysis (Fig. 5a and b). The identified topics involved waste treatment including wastewater (1378 occurrences), desalination (332 occurrences), groundwater including water management (863 occurrences), and climate change (795 occurrences).

3.3.1. Wastewater and water treatment

Researchers mostly focused on water quality and wastewater treatment with common keywords i.e., wastewater treatment (640 occurrences) and water quality (524 occurrences). Cluster exhibited that researchers of the GCC countries largely concentrated on advanced technologies including reverse osmosis process (205 occurrences), adsorption (138 occurrences) to remove heavy metals (340 occurrences), and dissolved impurities and to improve the water quality (524 occurrences). According to wastewater statistics, almost 54.4% of treated wastewater in UAE was used for irrigation in 2018.

3.3.2. Desalination

GCC countries have the highest desalination capacity globally and almost produce forty percent of the world's water desalination. Saudi Arabia and UAE are the market leader in the world of desalination. Oman is expanding its desalination market by about five

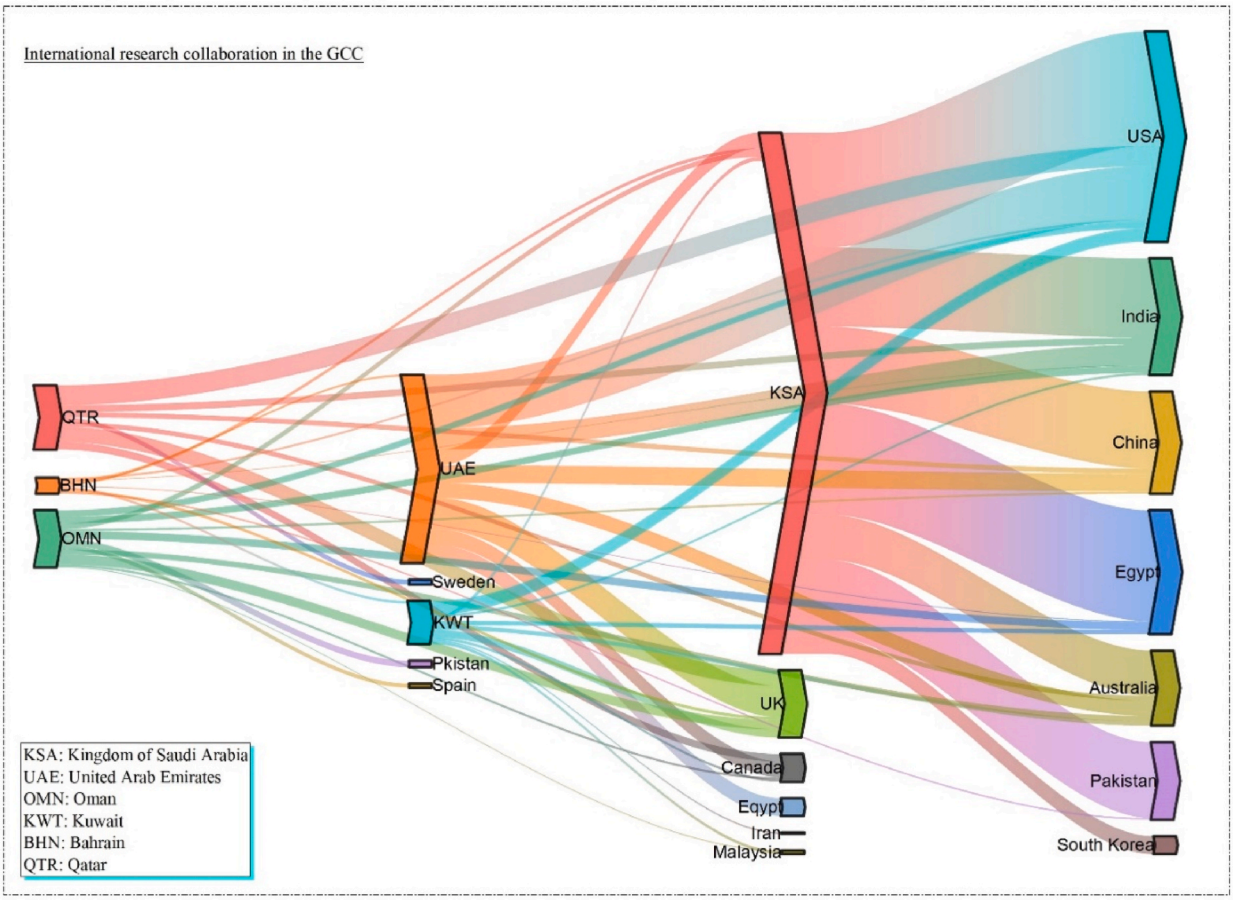

Fig. 3. International collaboration of the GCC countries in relation to water security and climate change impacts.

percent annually. A total of 332 publications on desalination processes were produced with a focus on life cycle assessment for sustainability and solar desalination to make the process economic. Currently, desalination plants are used to complement the water supply requirements in GCC countries [40,41]. There are more than 150 research articles on desalination. The references quoted in these studies mostly related to desalination's impacts on the life-cycle environment, desalination technologies, and mitigation strategies.

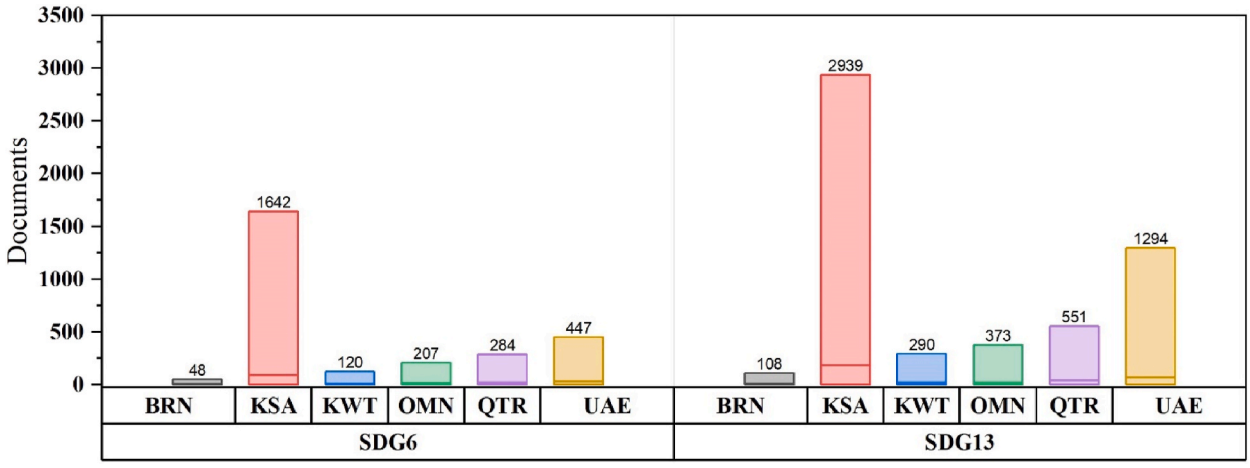

Fig. 4. Number of articles published related to SDG 6 and 13 in GCC countries.

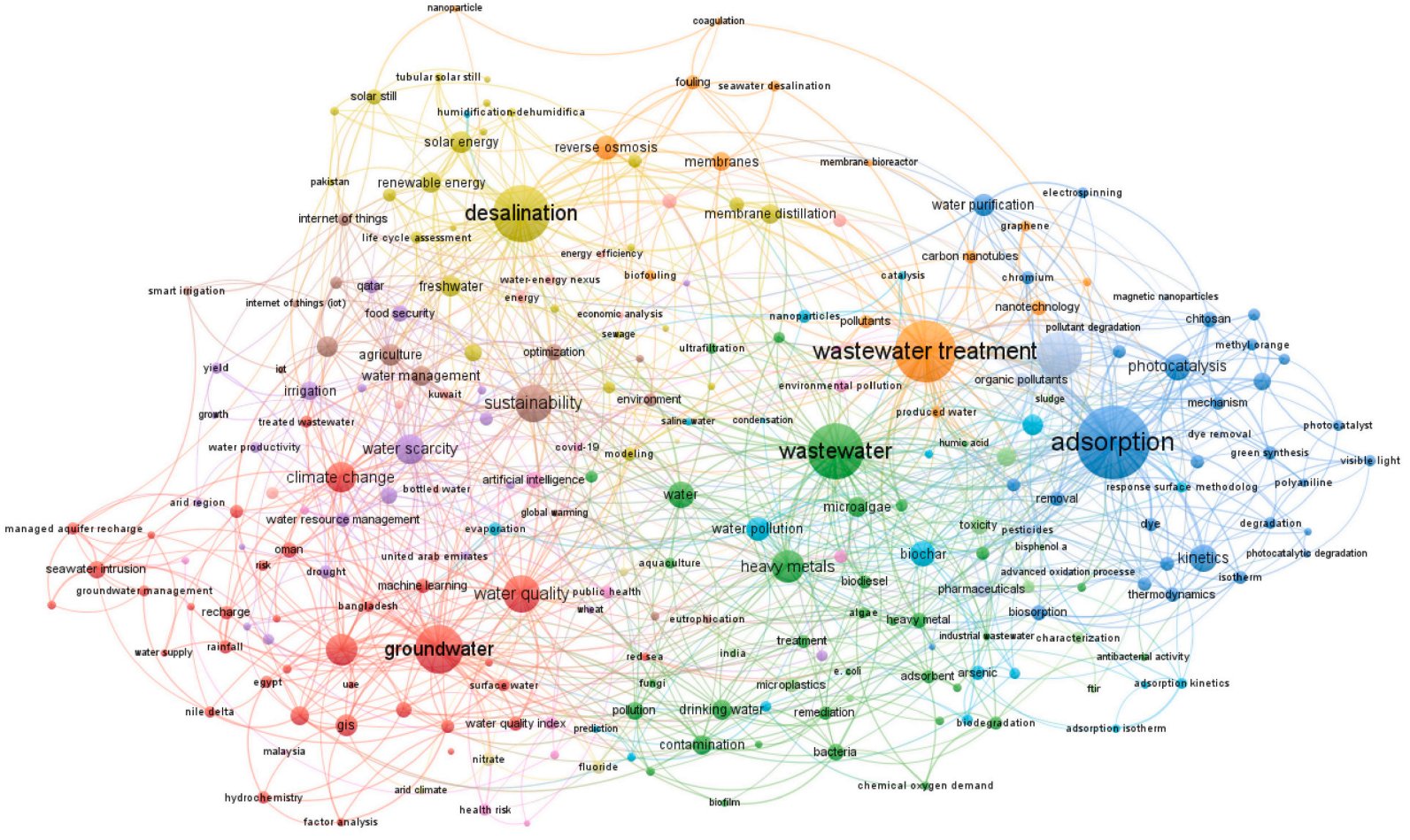

Fig. 5. (a) Frequent keywords on GCC countries water research concerning SDG 6 from 1979 to 2022. The circles, size, and text are proportional to the articles published in SDG 6 domain. Colors represent the cluster and the same color keywords display their occurrence in publication. (b): Frequent keywords on GCC countries climate research concerning SDG 13 from 1972 to 2022. The circles, size, and text are proportional to the articles published in SDG 13 domain. Colors represent the cluster and the same color keywords display their occurrence in publication. . (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

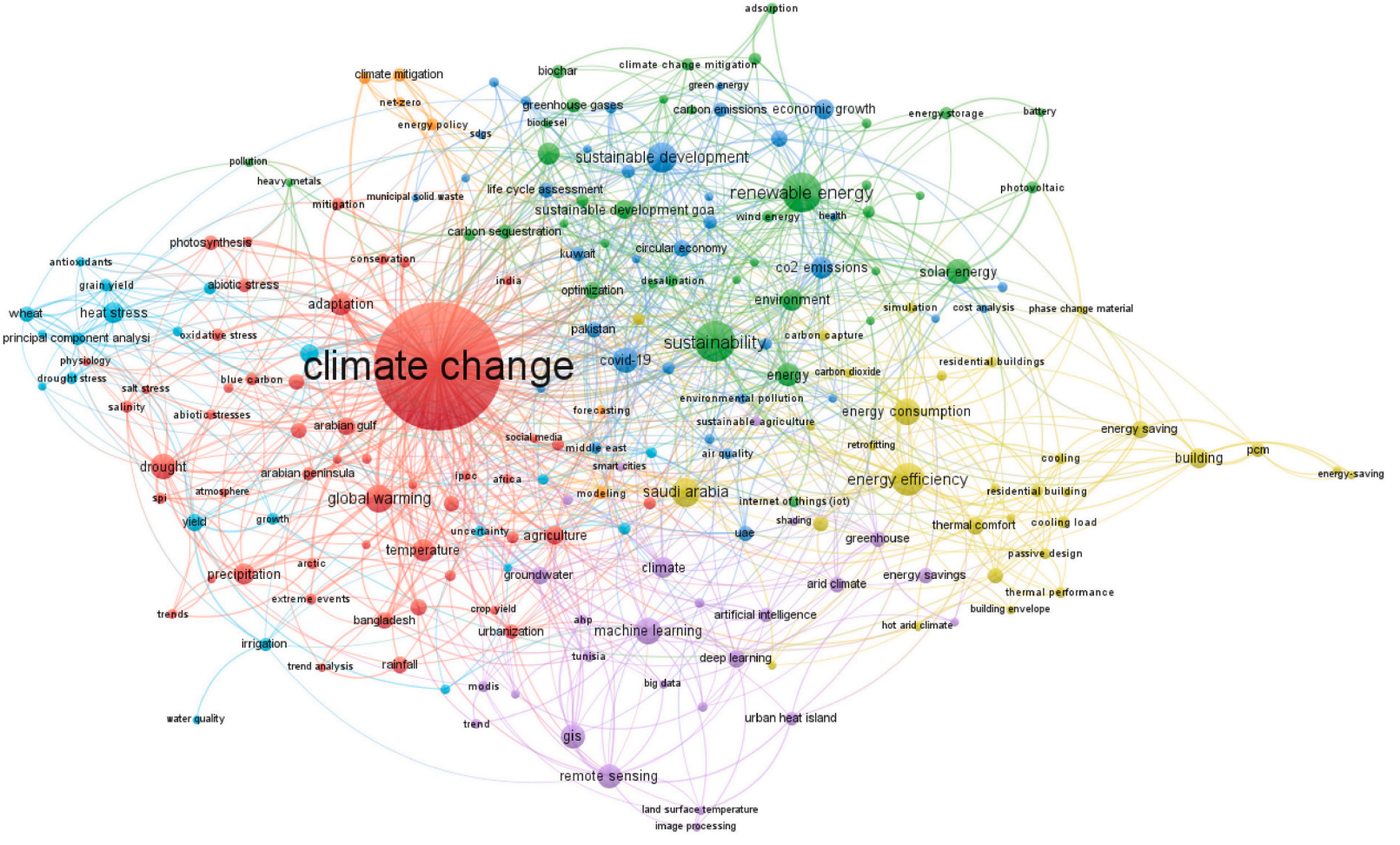

Fig. 5. (*continued*).

3.3.3. Groundwater

Groundwater is the primary source of natural water in the GCC countries. The total water storage in the shallow aquifers of the GCC countries is estimated at 131 BCM including Yemen [42]. These shallow aquifers represent vital sources of potable water supply in urban and rural areas, primarily in Oman and Saudi Arabia. Cluster analysis indicated that individual authors are working on groundwater quality (61 occurrences) and climate change impacts on groundwater resources (117 occurrences). The authors commonly used keywords such as water scarcity (71 occurrences), agriculture (206 occurrences), and salinity (102 occurrences) to address the water related problems in the region. Remote sensing techniques encountered in keywords revealed that researchers used multiple datasets to identify several geological and hydrological parameters and other information to study recharge conditions, contamination, and water quality mapping. Overexploitation of groundwater has accelerated seawater intrusion problems into coastal aquifers, caused a significant decline in groundwater levels, and increased the dryness of springs in GCC countries. Thus, large-scale studies utilizing advanced techniques may help to achieve the sustainability of groundwater resources in the region.

3.3.4. Climate change

Climate change and global warming represent an important topic in water and climate research (185 occurrences under SDG 6 and 795 occurrences under SDG 13). Climate change would impact GCC countries and hence there is a need to adapt to it. If the sea level rises by 1.5 m, Bahrain may lose its coastal land by up to 27% (IPCC's predictions: https://earth.org/data_visualization/sea-level-rise-by-2100-qatar-and-bahrain/). Many recommendations have been proposed to expand research and development to handle such challenges in the GCC countries [43]. The success of climate mitigation and adaptation plans in the GCC countries are dependent on their ability to shift toward renewable clean energy sources such as solar and wind energy. The rapid increase in the population and the notable improvements in living standards have imposed additional demands for water and energy in the GCC countries, specifically during the summer season. Significant subsidies on water and energy consumption are provided. As a result, it is estimated that GCC countries are emitting CO_2 higher than the average per capita in the world. This includes other industries and transportation emissions and is not limited to desalination [44]. According to the emission database [45], Saudi Arabia is ranked 11th in carbon emission per capita. Thus, the impact of climate change needs to be reviewed in multidisciplinary sectors to create different strategies for adaptation. There is a strong link between climate change and sustainable development (148 occurrences), adaptation (79 occurrences), agriculture (184 occurrences), and impact on temperature (265 occurrences).

3.4. GCC countries' contribution to support SDGs 6 and 13

Figs. 2 and 6 (a-c) exhibit the GCC countries' contribution to SDGs 6 and 13 from 1972 to 2022. There is an increase in publications after 2010 as compared to the last 4 decades, showing more scientific attention toward sustainability (6 a). Scientific contributions concerning SDGs could be assessed by the number of publications and/or citations. Scientific research on SDGs 6 and 13 topics, the average article citations of the research publications related to SDGs 6 and 13 during the period 2009 to 2014 is more than 30. There are exceptionally high citations under SDG 6 for publications after 1996. This boost may be due to the rapid growth in industrial and agricultural development activities in GCC countries. Researchers paid more focus to water issues that already imposed stress on water demands due to increased population [23,46]. From 2016 to 2022, the topics related to SDG 6 have attracted 18 citations on average per publication. For SDG 13, 28 citations are reported per publication. This indicates that more focus is devoted to climate actions in recent years. The evaluation of scientific research based on bibliometric analysis can be limited thus citations should be accumulated to assess the nature of targets and their progress towards the target [47]. From published material, it is observed that researchers devoted great attention to target desalination (SDG 6) because most of the water supply requirements in GCC countries are met by desalinated water (Fig. 6b). In the 1950s, Kuwait started the desalination process, and later it expanded to other GCC countries. In the 1970s, when desalinated technology was introduced at the commercial scale, the cost of producing one cubic meter was US$ 5.5 compared to the current cost of less than US$ 0.5 for large-scale reverse osmosis desalination plants. However, further research is still needed to reduce the energy consumption in desalination plants and solve problems related to membrane clogging. The use of renewable energy in desalination might address the problems related to high emission of greenhouse gases from desalination plants [48,49]. Significant research is currently in progress to improve efficiency and reduce the cost of desalination plants incorporating hybrid systems and using solar energy. Likewise, wastewater treatment is also getting high attention among researchers. According to statistical data from 2020, the GCC countries have more than ten thousand wastewater treatment plants. There is a high potential for the reuse of treated wastewater in GCC countries due to water scarcity conditions. The reuse of treated wastewater has a key role in managing water resources to balance the supply and demands [50]. Developments in treated wastewater technologies for municipal use and irrigation offer great opportunities to reduce the burden on other water resources. Fig. 6c depicts the interest of GCC countries in the sustainability of the region and in making a significant scientific contribution to SDG 13. The number of publications regarding climate change has increased significantly in the last six years. More than 1000 documents were published in 2021, showing significant contributions to achieving sustainable development goals. Furthermore, food security, economic growth, and drought are common keywords in GCC countries' climate research to strengthen SDG 13. The analysis revealed that the concerns related to adaptation (79 occurrences) to climate change impact are minimal in GCC countries because of public perception, evaluation, monitoring, information acquisition, and implementation of the measure. However, mitigation initiatives gained attention and several measures have been undertaken such as the expansion in clean production, energy efficiency systems, and use of renewable energy. In addition, the GCC countries operate state-level institutes to address environmental challenges and make a significant contribution (Table 2). In each state, individual institutes and executive agencies are working on the development of a sustainable future. Furthermore, the GCC countries also have a unified water strategy mission and vision to cope with the current challenges to sustainability (Fig. 7). The main

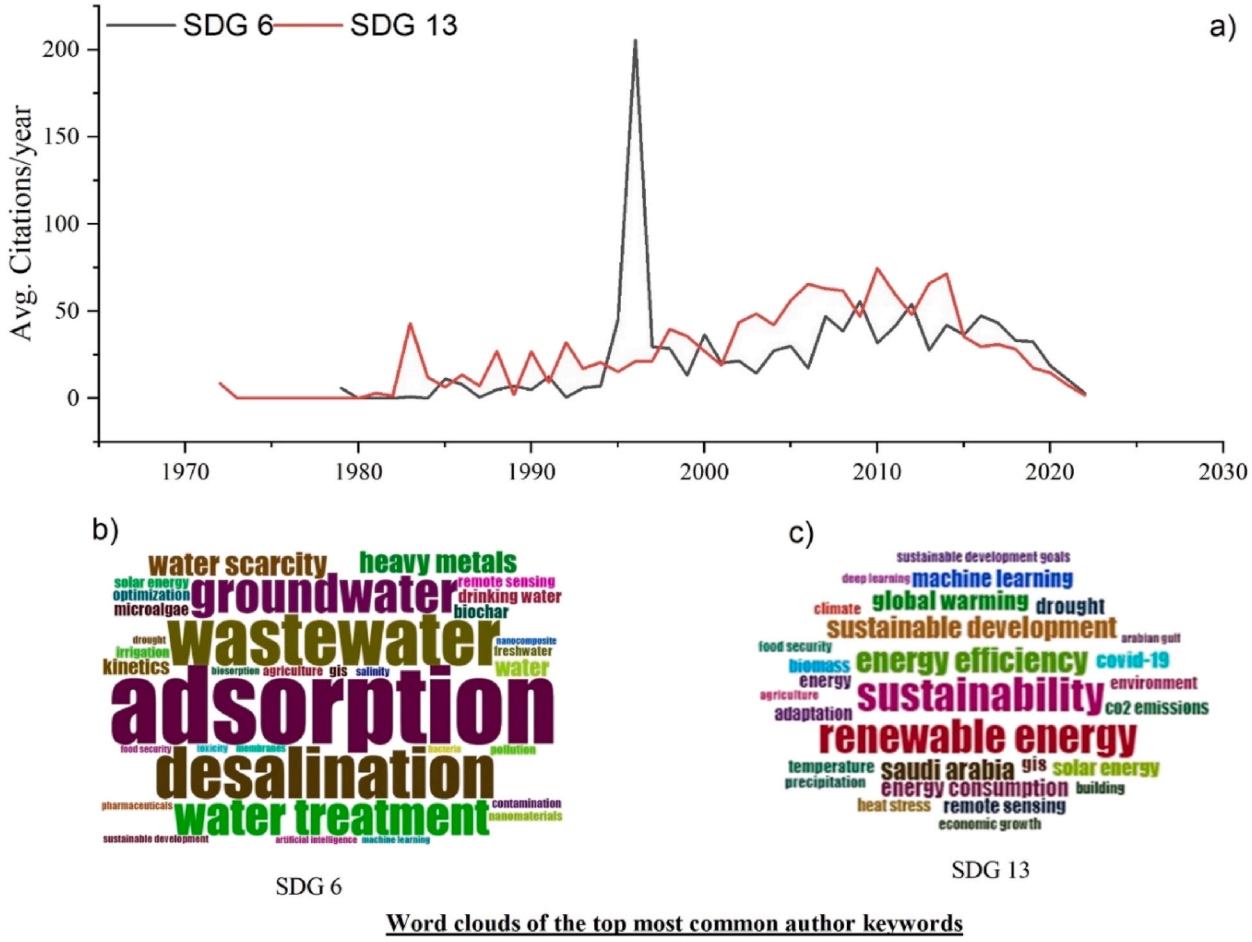

Fig. 6. a) Average citations/article from 1972 to 2022 and most common author keywords for (b) SDG 6 and (c) SDG (13).

Table 2
State-level institute working on water and climate actions.

Countries	Policy institute	Executive agency
UAE	Council of Federation	Federal Environment Agency/Ministry of Environment and Water Resources
Saud Arabia	Ministerial Committee on Environment	Presidency of Meteorology and Environment
Oman	Council of Ministers	Ministry of Environment and Climate Change
Kuwait	Environment public authority	Environment Public Authority
Qatar	Council of Ministers (Permanent Commission for Environmental Protection)	Supreme Council for the Environment and Natural Reserves
Bahrain	Environment and Wildlife Affairs	Public Commission for the Protection of Marine Resources, Environment and Wildlife

objective is to ensure high standards for water supply, effective water governance, raising water awareness, taking adaptation measures, promoting research and development, and enhancing institutional capacity. The GCC countries are also working on taking climate action and comprehensive progress has been made by setting the targets. For example, Saudi Arabia started a green initiative, UAE is working on climate impacts assessment, Oman has a carbon reduction plan, and Qatar has set its target to reduce greenhouse gases by 25% by 2030 (Fig. 7). To support SDGs, the GCC countries systematically work on improving the efficiency of wastewater treatment plants and desalination systems.

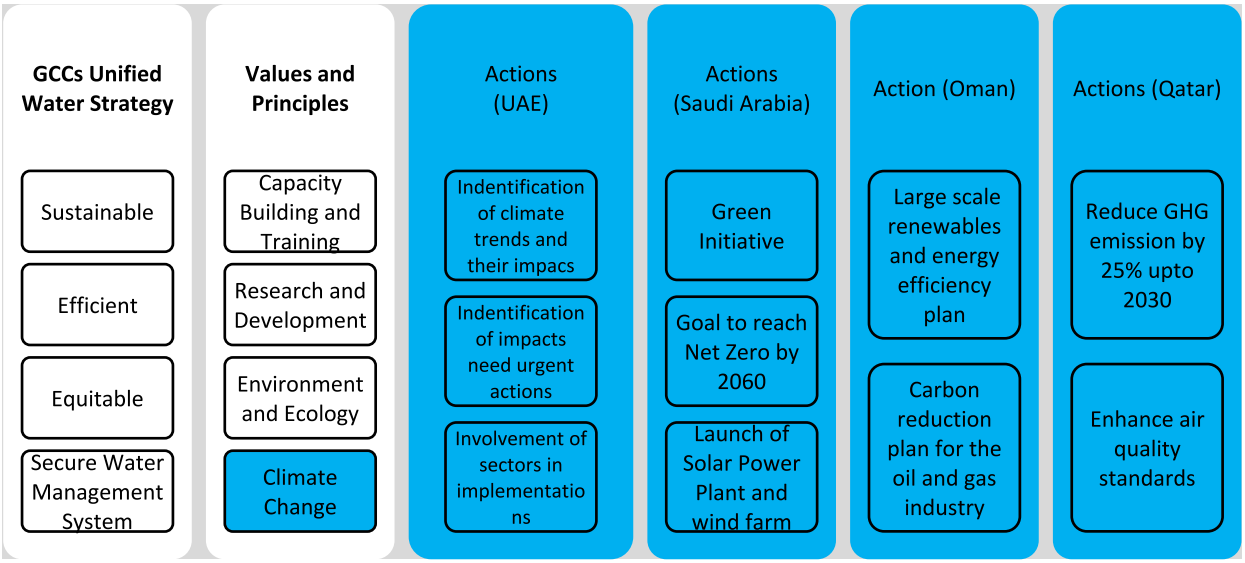

Fig. 7. GCCs strategic theme for sustainability.

4. Conclusions

The sustainable development goals (SDGs 6 and 13) were comprehensively studied using text mining and bibliometric analysis to assess the contributions of the GCC countries to water and climate research related to regional and global sustainability. Documents related to SDGs 6 and 13 keywords were extracted online from the Scopus database based on the records from 1972 onward. Text mining and bibliometric analysis are sufficient for analyzing the implementation of SDGs. Results revealed that researchers and institutes in the GCC countries pay full attention to water and climate sectors. Saudi Arabia and UAE have the highest water and climate research outcomes in the recent years as compared to other GCC countries. The United States and China are the top international collaborators with the GCC countries concerning SDGs 6 and 13. Analysis indicated that international collaboration has a better impact as compared to single-country authorship. Research hotspots of GCC countries' water and climate research include wastewater treatment, climate change, and groundwater including its quality, etc. This orientation showed that GCC countries' water and climate research has a significant contribution to strengthening SDGs 6 and 13. Adsorption, heavy metals, and water scarcity represent the focus of researchers, showing that they remain a key issue for water quality. Advanced technologies, such as artificial intelligence and remote sensing, have been applied to study water contamination, water quality, groundwater fluctuations, the impact of climate change on water resources, temperature variation, rainfall patterns and hence supporting SDGs 6 and 13. The researchers also paid attention to seawater intrusion in coastal aquifers and its impact on groundwater quality, small-scale agriculture, and heavy metal contamination. In addition, the GCC countries are located in an arid region. Significant population growth, fast urbanization, and agricultural projects are among the human factors that contribute to the pressure on already overburdened water supply systems. There is no other option for the GCC countries but to find new water sources including the utilization of slightly to medium brackish groundwater in agriculture activities. There is also a need to take a holistic approach to ensure water and food security. Water security should be addressed from both a development approach and a risk-based approach considering climate change (e.g., emergency production) to establish an integrated water resources management system.

Author contribution statement

Mohsen Sherif: Conceived and designed the experiments, Wrote the paper.
Muhammad Abrar: Analyzed and interpreted the data; Contributed materials, analysis tools or data; Wrote the paper.
Faisal Baig and Saifudeen Kabeer: Analyzed and interpreted the data; Contributed materials, analysis tools or data; Wrote the paper.

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Data availability statement

The data used for this research is free available on https://www.scopus.com/.

Declaration of interest's statement

The authors declare no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e14584.

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