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Research Trends and Hotspots on Karst Water Resource in Iran and the World

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Abstract

Karst groundwater is one of the primary water resources in most territories of Iran where karst topography is strongly featured. Understanding the key knowledge and research status of karst is an important prerequisite for subsequent research. This study aimed to examine the literature characteristics and research hotspots of karst based on Science direct database from 1998–2021 and scientific information database (SID) of Jihad Daneshgahi and Iranian Research Institute for Information Science and Technology (IranDoc). With systematic bibliometric analysis, insights were made into multiple aspects including research output, subject categories, journals, countries/territories, hotspots and research trends. The results showed that the general trend of global scientific publications in karst research has a negative slope with a negative growth rate of 0.91. But the trend of Iranian publications, with a positive slope and coefficient determination of 0.87 and a positive growth rate of 1.2 percent, has been increasing. The results of thematic classification of publications in the world showed that the most articles with 75.96% belong to research articles and the lowest to conference articles and editorials. Iranian articles also belong to the first order of importance to research articles with 91%, which is a larger share of the total articles than global articles. The results of analysis of the most important scientific journals related to karst showed that these journals have a very high h-index and JCR in Q1 and Q2. Keywords related to the intrinsic, structural characteristics and karst water resources systems had the highest frequency and the lowest frequency related to karst hazards.

Keywords: Geological structure, Hotspots, Karst hazards, Research trend, Water resources

1. Introduction

Karst aquifers are one of the most important sources of drinking water in the world. Therefore, recognizing the different characteristics of the karst phenomenon is important from a fundamental point of view and in terms of water supply required by humans. Stress on groundwater resources in quantitative and qualitative terms has increased significantly in recent decades (Wada et al., 2010), in terms of water quantity, due to over-agriculture (Aeschbach-Hertig and Gleeson, 2012) and in terms of quality due to contamination by fertilizers (Foley et al., 2011). Due to the arid and semi-arid climate and inadequate spatial and temporal distribution of rainfall, groundwater resources in Iran are of particular importance. On the other hand, due to the quantitative and qualitative limitations of alluvial water resources and due to the wide spread of karst formations in Iran, studies and research of karst water resources are of special importance.

Sustainable water resources management is a vital concern of most countries in the world. Only 3% of the total water on earth is considered as fresh water resources and about 30% of it is available as groundwater (Shiklomanov, 1993). Karst aquifers are responsible for supplying drinking water to 25% of the world's population (Ghasemizadeh et al., 2012). Globally, 15.2% of the earth's surface is covered by carbonate formations. The highest karst percentages are in Europe

(21.8%), followed by North America (19.6%), Asia (18.6%), Africa (13.5%), Australia and Oceania (6.2%) and South America (4.3%). Carbonate rocks are present in all climatic zones. The highest percentage is in the moderate zone with 19.1% followed by cold weather (16.8%); Dry (14.8%); tropical (8.8%) and polar (7.7%). The coverage of karst formations in Iran is 11% (Afrasiyabi,1998). Also according to (Goldscheider et al., 2020) Iran is in the seventeenth order with a large area of karst formations.

According to Parise et al. (2018), karst issues are divided into four main groups. 1- Intrinsic and structural characteristics such as: geology, geomorphology and karst speleology; 2- Karst hydrology; 3- Karst modelling; 4- Hazards and karst management.

The study of Intrinsic and structural characteristics of karst and their features is not just of interest in karst science, but has significant implications in many other fields. In addition to the economic aspects of karst research, the analysis of karst features may offer insights into other sectors of the earth sciences. The cave environment has been recognized as a potential platform to create analogues for space exploration missions and caves are ideal sites for training astronauts. Caves have been recognized as sites where remarkable remains and deposits are preserved (Sasowsky and Mylroie, 2004).

Karst aquifers often provide abundant groundwater reserves, which are invaluable resources relevant to human health, food security and industry. The importance of aquifers with karst permeability, which already supply around a quarter of the global demand for drinking water, is increasing. In particular, groundwater in the Mediterranean basin is generally more abundant in karst than in other aquifers and has been extensively exploited (Bakalowicz, 2005; Ford and Williams, 2013).

Based on the complex properties of karst, various techniques and tools related to conventional, and modified methods (such as hydrological and hydraulic methods, geophysical and geological methods, modelling techniques and tracer experiments) were used by researchers to understand the behaviour of Karst aquifers. Meanwhile, the interaction of surface water and groundwater plays an important role in understanding the hydrological behaviour of a basin. In this regard, topographic, geological and morphological features are important (Bayless et al., 2014).

One of the necessary tools for karst water resources management is awareness of the components affecting karst water resources; This can be done by modelling the quantitative and qualitative components of karst aquifers and using estimation and forecasting models. Predictive models indicate that rising temperatures and the consequent quantitative and qualitative pressures on karst water resources are likely to increase significantly in the future (Christensen et al., 2007). In order to predict the behaviour of aquifers based on hydrological changes, groundwater models have been developed by hydrogeologists and water resources scientists. In addition, some models have been developed for chemical analysis of water quality and to simulate the fate and transmission of pollutants (Manda and Gross, 2006; Theilen-Willige et al., 2014). Modelling, hydrographic analysis, and hydrogeological mapping are common techniques used to evaluate the interaction of surface and groundwater in karst (Fleckenstein et al., 2010). Also, field observations, leak measurements, and hydro chemical methods, such as natural isotopes, hydro chemicals, tracers, as well as hydrometric and geophysical analysis, are useful tools that can be used to describe the interaction of surface and groundwater in karst.

Using Geographic Information System (GIS) as a tool in groundwater modelling can be useful. Because all parameters such as rainfall distribution, recharge and groundwater discharge as well as land cover were defined in a spatial context (Singh and Fiorentino, 2013). Several researchers have used this powerful tool directly or in parallel in integrated approaches (Alonso- Contes, 2011; Nampak et al., 2014; Dar et al., 2010).

In recent years, the use of geophysical methods (such as resistance, electromagnetic, radiometric) or remote sensing has expanded (González-Pinzón et al., 2015; Rugel et al., 2016). In groundwater hydrology, hydraulic conductivity, quantifies the ability of soil to transfer water. Depending on the different materials of the aquifer, the hydraulic conductivity can vary from 10 cm / s for sand to

10^{-10} cm / s for shale. The hydraulic conductivity of karst limestone is the highest compared to many other aquifers (Smith et al., 2016). Therefore, one of the issues in the study of karst water resources is the issue of pollution. Agricultural, industrial, residential, commercial and urban development have been considered as the main sources of karst groundwater pollution in recent decades (Fetter, 2018; Wakida and Lerner, 2005). In particular, leaks from storage tanks, chemical leaks, landfills, fertilizers and pesticides, sanitation systems, untreated waste and sewage disposal are some of the main sources of pollution from human activities (El Alfy and Faraj, 2017; Lapworth et al., 2012; Yao et al., 2012; Panagiotakis and Dermatas, 2017; Vidal Montes et al., 2016).

The presence of karst landscapes in large parts of the world, and karst aquifers supplying important regions and many metropolitan areas with drinking water, is evidence of the great significance of karst and the need to preserve karst landscapes and their natural resources. At the same time, karst is recognized as an extremely fragile environment, susceptible to a variety of natural and anthropogenic hazards (Gutiérrez et al., 2014). Sinkhole hazards are the most typical geohazard in karst. The most worrying, in terms of likely damage to human activities and infrastructures, are collapse and cover-collapse sinkholes, which generally occur in a catastrophic way with little or no warning.

The purpose of this study is to investigate the trend of karst research publications in Iran and the world, to identify research fields and to determine the less considered and neglected domain in domestic research, based on the Science Direct database, (SID) and (Iran Doc) database.

2. Materials and Methods

2.1. Data Source

The data were retrieved from the Science direct in the period 1998 to 2021 and SJR[1] index from https://www.scimagojr.com as well as scientific information database (SID) of Jihad Daneshgahi and Iranian Research Institute for Information Science and Technology (IranDoc).

[1] SCImago Journal Rank (SJR) indicator

2.2. Data Analysis

A total of 22416 publications were obtained and with following aspects analysed intensively:(1) Distribution of International Karst-related publications (2) Karst-related publications from Iran; (2) Distribution of subject categories; (3) Core journals; (4) Distribution of Iranian articles related to karst; (5) Frequency of karst related articles in Middle East and Countries around Iran; (6) Hot topics and research trends. Bibliometric techniques, including citation analysis, five-year impact factor, JCR classification, coverage period and h- index were used to evaluate and interpretation of the results.

3. Results and Discussion

The development trend of global publications related to karst in each year is shown in Figure 1. The number of publications has decreased significantly from 1998 to 2021 with a negative average growth rate of 91%. The cumulative amount of publications with an upward trend and with a coefficient determination of 0.999 indicates the exponential growth of the cumulative amount of publications related to karst. From 1999 until 2021, the true value of the cumulative number has clearly exceeded the theoretical value (curve fitting line), which shows great potential for karst research in the world. In this time frame, the cumulative amount of karst-related publications was much greater than the theoretical fit line.

Figure 2 shows the development trend of karst-related publications in Iran. As can be seen, the development of publications with a positive trend and 0.87 coefficient of determination and a positive growth rate of 1.2%, Shows the proper attention of the Iranian scientific community to karst research. But this issue has faced a negative trend on a global scale and showed a negative growth rate of 0.91. From 2005 to 2011, as well as in 2021, the true value of cumulative numbers has clearly exceeded the theoretical value, which shows great potential for karst research in Iran. Between 2012 and 2020, the cumulative amount of karst-related publications was less than the theoretical fit line.

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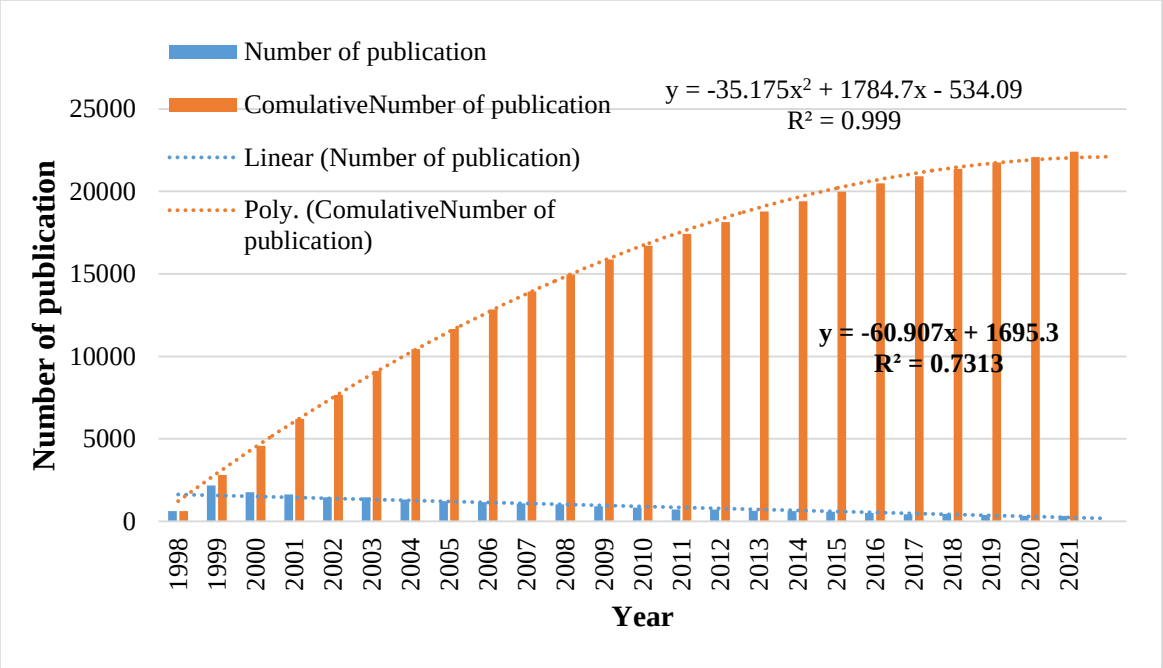

Fig. 1. Development trend of international Karst-related publications

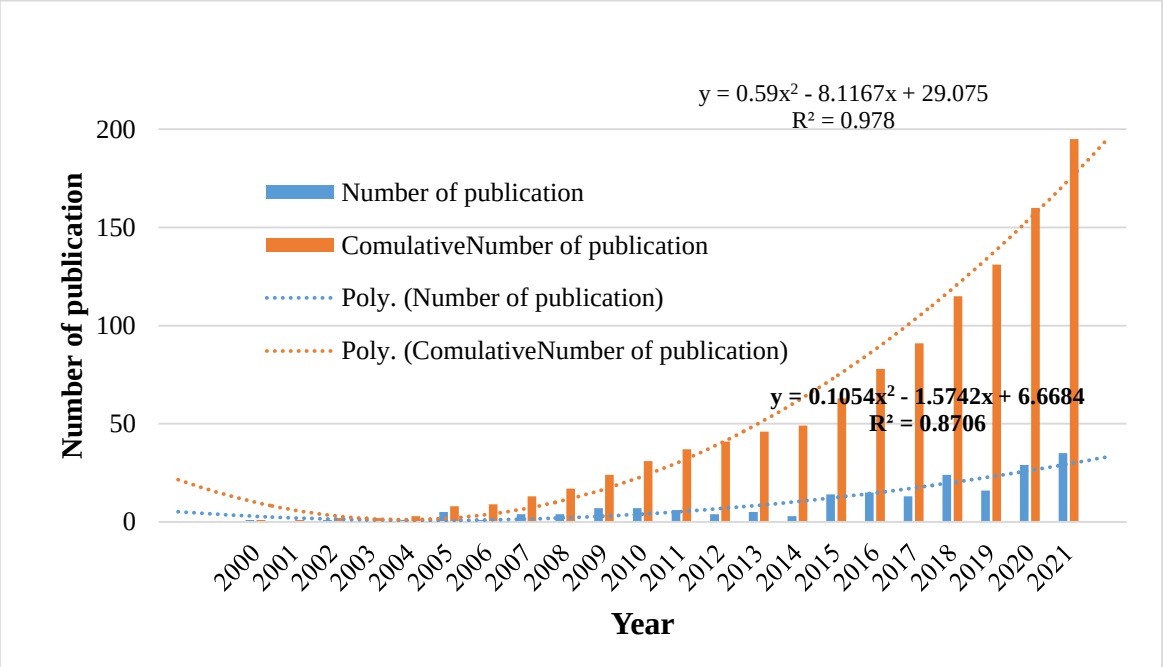

Fig. 2. Development trend of Karst-related publications from Iran

Thematic classification provided by the Science Direct database was used to analyse the distribution of thematic categories, in which each article was assigned to at least one thematic category. Figure 3 shows the distribution of karst-related articles in eight categories. These categories include review articles, research articles, encyclopedia, book chapters, conference abstracts, editorials, short reports, and others. The highest frequency with 75.96% related to the category of research articles and the lowest to conference papers and editorials. Book chapters and encyclopedias were also significant with 6 and 9.6 percent.

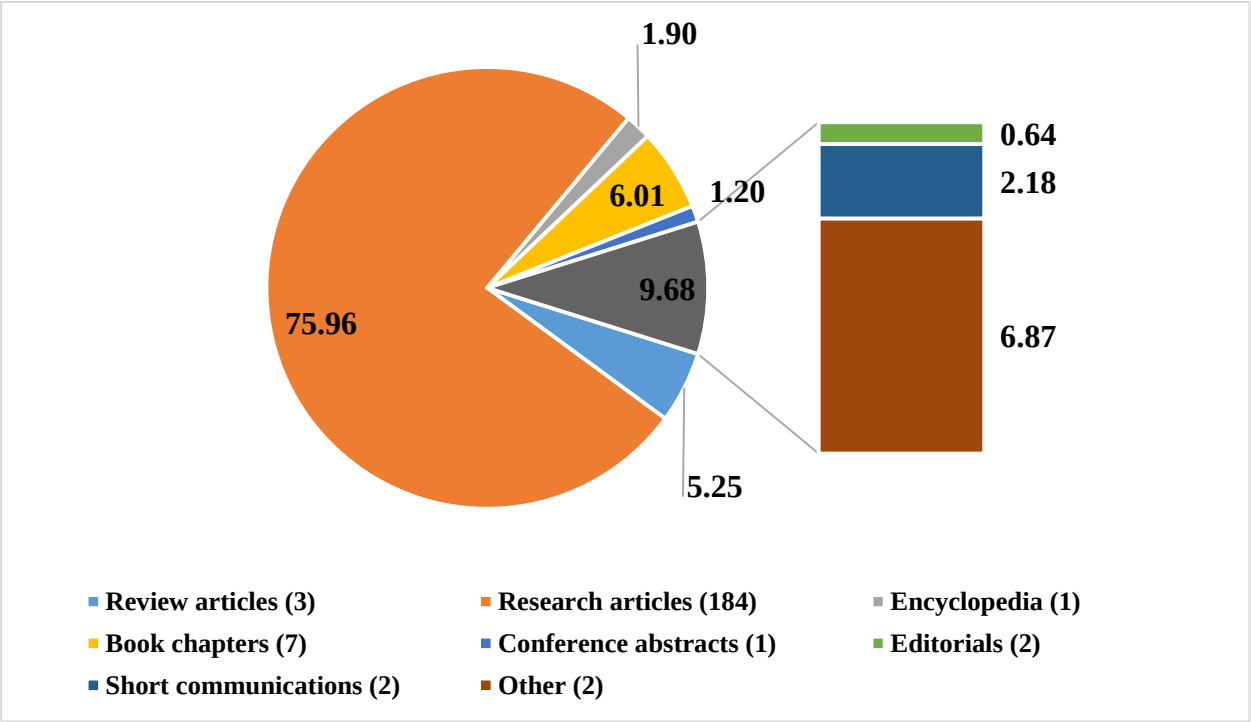

Fig. 3. Distribution of International articles related to karst

Regarding the distribution of Iranian articles that is presented in Figure 4, the high volume of 91% of research articles is significant, which has a larger share of the total articles than global articles. Articles in the book chapters and encyclopedias, with an average of 3 to 3.5 percent, had a smaller volume than the number of international articles. The top 14 core international journals in which karst-related articles have been published were listed in Table 1, the total citation rate of all these journals, all of which was greater than 856.

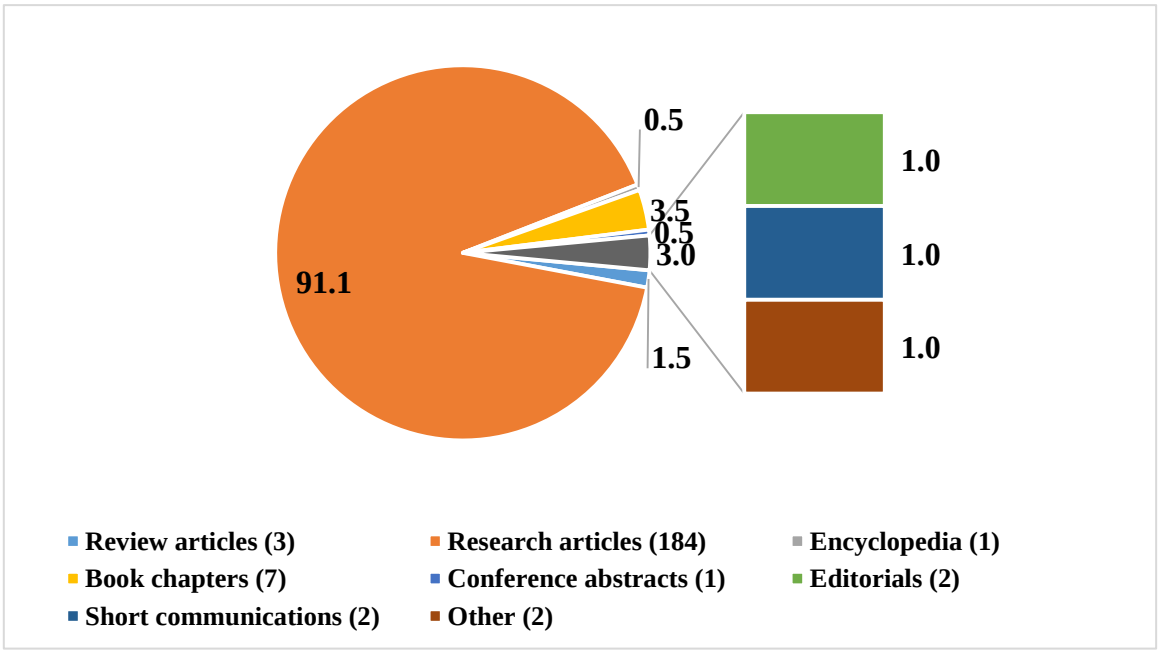

Fig. 4. Distribution of Iranian articles related to karst

Table 1. Characteristics of the 20 core journals in the field of karst research

Row	Journal Name	IF5	H-INDEX	TC	Coverage	JCR Partition
1	Journal of Hydrology	5.722	226	15250	1949, 1963-2020	Q1
2	Ore Geology Reviews	3.809	97	5534	1986-2020	Q1
3	African Earth Sciences	2.046	76	1920	1983-2020	Q2
4	Geochemical Exploration	3.746	87	2522	1972-2020	Q1
5	Science of The Total Environment	7.963	244	106837	1970, 1972-2021	Q1
6	Marine and Petroleum Geology	4.348	116	5823	1984-2020	Q1
7	Asian Earth Sciences	3.449	125	4424	1997-2020	Q1
8	Geomorphology	4.139	159	5052	1984, 1987-2020	Q1
9	Tunnelling and Underground Space Technology	5.915	98	6440	1986-2020	Q1
10	CATENA	5.198	128	7175	1973, 1975-2021	Q1
11	Quaternary International	2.130	106	4556	1989-2020	Q1
12	Cretaceous Research	2.176	69	1597	1980-2020	Q1
13	Contaminant Hydrology	3.188	100	856	1986-2020	Q2
14	Chemical Geology	4.01	202	4857	1966-2020	Q1

In terms of h-index, Journal of Science of the Total Environment was the highest with 244, followed by Journal of Hydrology (226) and Chemical Geology (202). All of these major journals in the JCR classification were in the Q1 and Q2 categories, indicating the relatively high quality of karst research. Forest Ecology and Management and the Journal of Hydrology were the oldest related journals in terms of time coverage they have been published.

In order to analyse the attention of the Middle East and peripheral countries of Iran to the subject of karst research, 20 countries investigated and the results were presented in Table 2. The status of karst-related articles in Iran is superior to that of Middle East countries, followed by Egypt, Jordan and Saudi Arabia. Other countries have given less importance to the karst issue due to the small area of the country and consequently the low coverage of karst formations. In the countries around Iran, Russia is at the top with 310 publications, which is not far from Iran due to the area and capacity of karst resources. According to (Goldscheider et al., 2020) Russia has 185.710 million square kilometres of karst formation, which is more than the total area of Iran.

Meanwhile, Turkey, with an area almost equal to Iran and the area of karst formations larger than Iran (40% of Turkey covered by karst, Nazik et al., 2019) has been almost equal to Iran and has published 198 cases.

Table 2. Number of karst related articles in Middle East and peripheral countries of Iran

Row	Name	Number of articles	Row	Name	Number of articles
1	Egypt	106	12	Palestine	1
2	Iran	202	13	Kuwait	13
3	Iraq	12	14	Qatar	22
4	Saudi Arabia	78	15	Bahrain	3
5	Yemen	6	16	Kazakhstan	17
6	Syria	7	17	Turkmenistan	1
7	Jordan	102	18	Russia	310
8	United	32	19	Azerbaijan	2
9	Libya	2	20	Armenia	5
10	Lebanon	39	21	Afghanistan	2
11	Oman	24	22	Turkey	198

3.1. Karst-related keyword analysis

In this study, based on the thematic classification of karst research used by Parise et al. (2018). We examined 24 keywords that had more frequency, among which keywords related to karst intrinsic properties and structural characteristics and karst water resources systems (hydrology) had the highest frequency and the lowest frequency were related to hazards and karst modelling Table 3.

Table 3. Frequency of 23 top keywords in the field of karst research

Key word	Frequency	Key word	Frequency
Karst geohazards	0.2	karst cave	3.3
Karst subsidence	1.3	Karst classification	3.4
karst watershed	1.5	karst groundwater	3.7
Karstification	1.6	Karst properties	5.9
karst infiltration	1.9	karst features	6.0
karst water pollution	1.9	karst development	8.3
karst water exploration	1.9	Karst potential	8.6
karst hydrology	2.0	karst structure	8.7
karst hydrological	2.5	karst water system	8.7
karst aquifers	2.7	karst Characteristics	8.8
Karst flooding	2.9	karst region	11.0
Karst engineering	3.1	karst cave	3.3

An example of a keyword growth trend in karst-related articles was presented in Figures 5 and 6. Noteworthy was the harmonious growth of keywords that were thematically related to each other. As can be seen from Figure 5, the development trend of the use of two words related to water resources, namely "Karst water system" and "Karst ground water", were incremental and the trends follow each other exponentially with coefficient of determination more than 0.97%. Regarding the keywords related to the intrinsic characteristics of the karst and the karstification process, the coordination in the growth of the use of these words with the exponential growth and explanation coefficient of 0.98 has been shown.

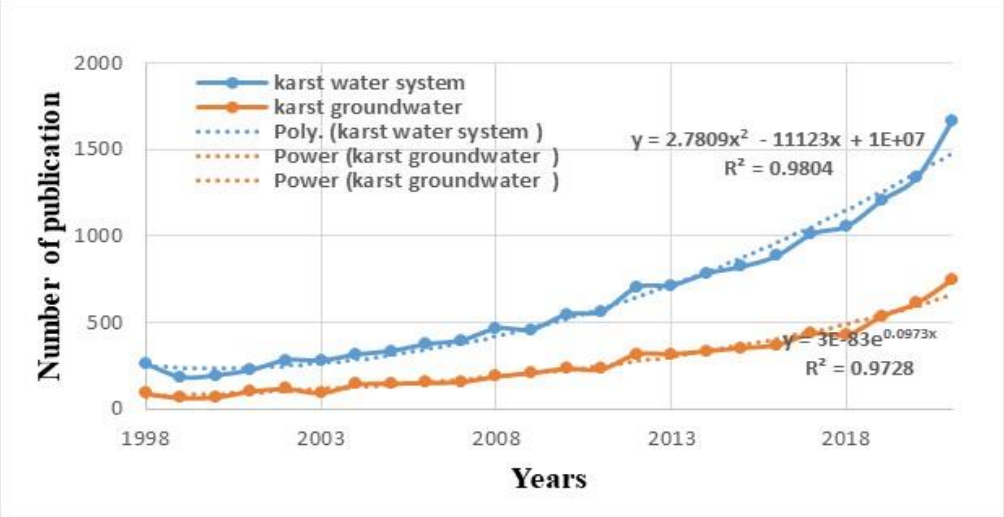

Fig. 5- The growth dynamics of top 2 high-frequency keywords related to karst water resource

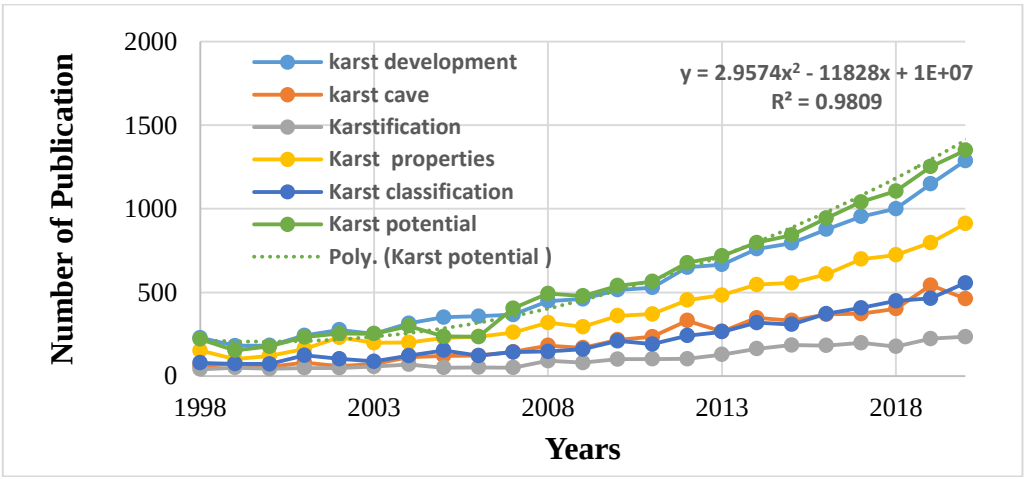

Fig. 6. The growth dynamics of top 6 high-frequency keywords related to intrinsic properties

3.2. Karst research publications in Iran:

In the last two decades, numerous researches on karst phenomenon have been conducted from different perspectives, which include various fields of structural studies based on knowledge, quality and quantity of water resources in karst, hazards and other cases. Most of these researches have been done in the form of student dissertations. In this research, first, based on the archival method and referring to the database of (SID) and (Iran Doc), The classification of dissertations, articles and published reports in the field of karst has been discussed in domestic journals and related conferences in the last two decades. The trend of publishing dissertation related to karst from 1989 to 1400 presented in Figure 7. As it is clear, the trend of publications from the beginning of the study period to 1385 has an increasing trend with a gentle slope, but from 1385 to 1395 shows an upward trend with a steep slope and again from 1395 to 1400 declining trend was observed in the publication of karst dissertations. Thematic classification of database publications is presented in Figure 8. As can be seen from the figure, 73% publications (SID) were related to the structure and nature of the karst phenomenon, and the issue of quality and quantity of water resources in karst aquifers has accounted for a total of 27% of the publications.

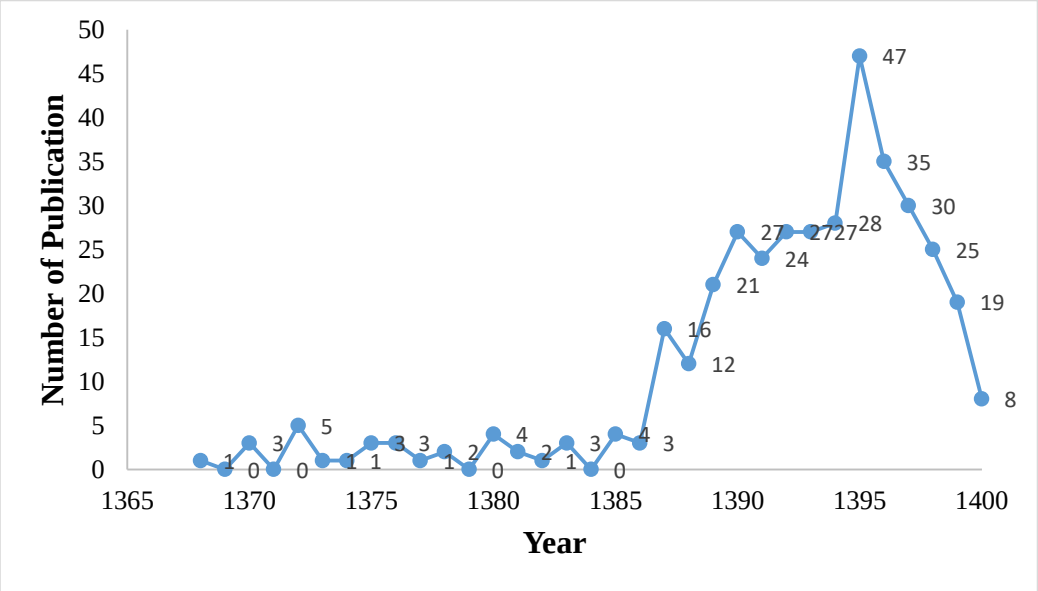

Fig. 7. Thesis growth trend in the field of karst based on IranDoc database (381 cases)

Frequency of dissertations published on the field of karst are given in Fig. 9. Among the topics of master's and doctoral dissertations, 49% of the dissertations have deal with the quantity and quality of karst water resources (hydrology) and 39% have deal with the issues of understanding the structures and nature of the karst phenomenon. Modelling and hazards have also made a small contribution to the study of the research period.

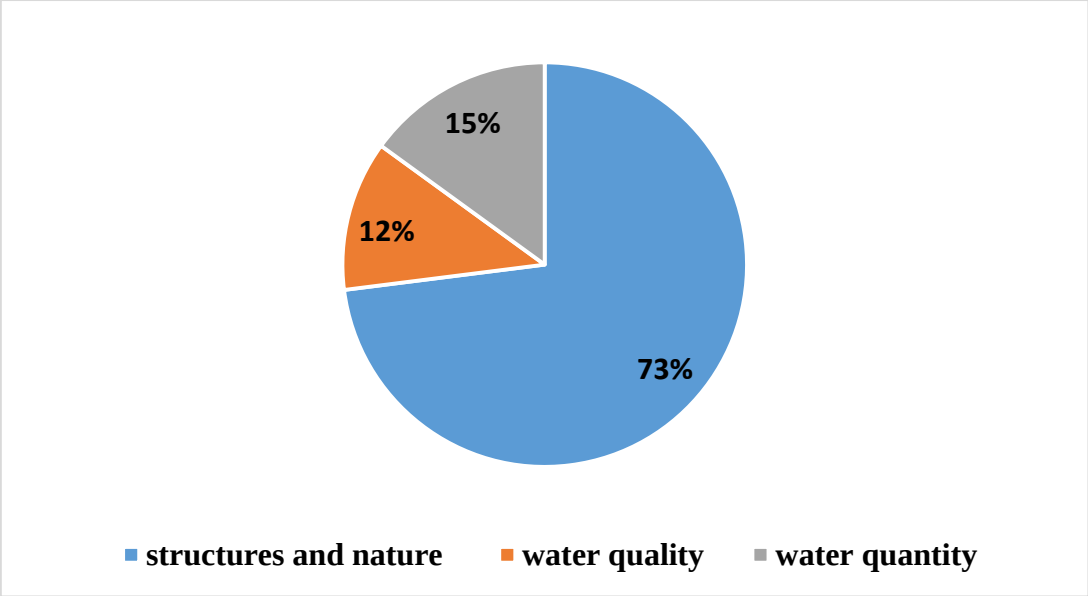

Fig. 8. Frequency of research articles published on the subject of karst in the (SID) database in 1379-1400

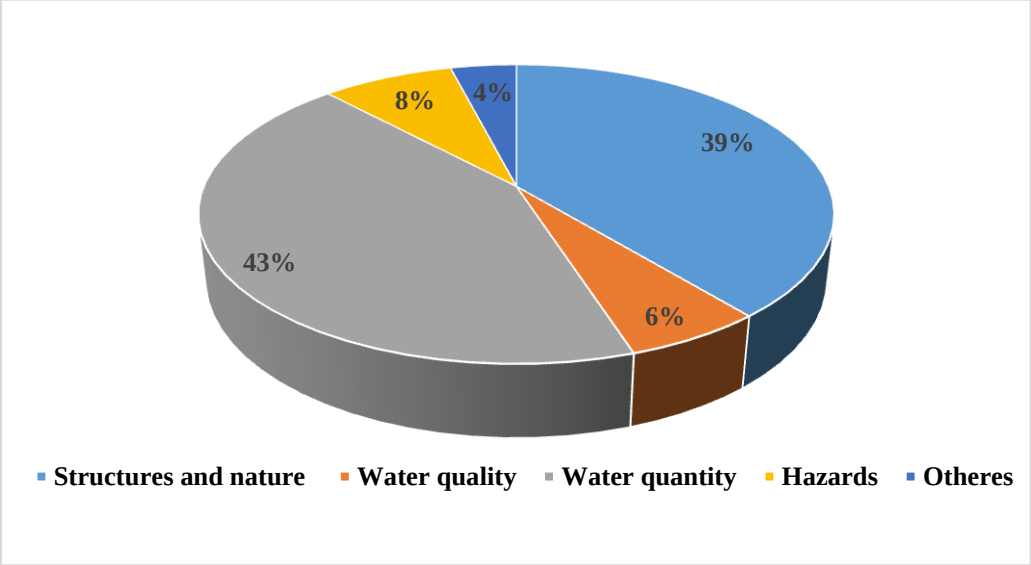

Fig. 9. Frequency of dissertations published on the field of karst in the (Iran doc) database in 1379-1400

4. Conclusion

This research is a systematic bibliographic analysis of texts related to the karst phenomenon, based on the Science Direct database and the JCR index from https://www.scimagojr.com during 1998-2019 as well as scientific information database (SID) of Jihad Daneshgahi and Iranian Research Institute for Information Science and Technology (IranDoc). The overall results showed that the scientific efficiency of karst research on a global scale in the first decade of the study period with an average of 1360 cases, has a significant amount. But in the second decade, with an average of 573 cases, it has had a decreasing trend. The general trend of publications in this database is also a decreasing trend. However, regarding the publications of Iranian researchers in this database, the trend of publications has been increasing with a positive slope, which shows that Iranian researchers pay more attention to the karst subject. The summary of thematic classification of publications showed that globally, the most articles with 75.96% belong to the category of research articles and the lowest to conference articles and editorials.

In Iranian journals, research articles were given the first rank, but the percentage and volume of 91% of research articles in Iran is significant and compared to international articles, it has a larger share of all articles. The

reason for increasing attention to karst research in Iran compared to the world can be due to being in an arid and semi-arid climate and the continuous occurrence of drought in the last two decades. Therefore, as an alternative way to supply drinking water resources, more attention has been paid to karst aquifers. In the analysis of 14 scientific journals in which karst-related articles have been published, the very high h-index coefficient and JCR classification in Q1 and Q2 were significant. Regarding the frequency of keywords, it is noteworthy that the keywords related to the intrinsic, structural characteristics and karst water resources systems had the highest frequency and the lowest frequency was related to the keywords related to karst hazards.

5. Acknowledgments

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6. Conflicts of Interest

No potential conflict of interest was reported by the author.

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