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RESEARCH ARTICLE

Analysis of hydrogeoseismological anomalies observed in groundwater during earthquakes

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Abstract

This bibliometric analysis aims to research articles, conferences, and books published on groundwater hydrochemical anomalies due to earthquakes during 1970-2024 in fourteen seismically active countries. The data used in this analysis were obtained from the online version of the Scopus database and corresponded to 379 publications according to the selection criteria. Bibliometric analysis showed that all articles were published in English, with the most publications coming from Japan, India, Germany, China, Turkey, Taiwan, Italy, the Russian Federation, and the United States.

Keywords: Groundwater; earthquakes; anomalies; precursor; groundwater

1. Introduction

An earthquake is one of the most terrible and destructive forces of nature, which causes disasters and causes enormous material damage to humanity. Therefore, many studies are being conducted in front of science today to deepen the knowledge about the processes that cause earthquakes, as well as to search for indicators of strong earthquakes. Currently, the problem of earthquake prediction is of national economic and social importance, and the works of many leading scientists from the USA, Japan, China, Armenia, India, Russia, Italy and other countries are devoted to it[1-6]. This extensive research is being carried out in this direction using various methods, including seismological, geophysical, astrophysical, biophysical, hydrogeochemical, and others.

In recent years, the problem of earthquake prediction has drawn the attention of researchers to various hydrogeochemical effects that precede and accompany catastrophic earthquakes. These effects were first detected in the 1966 Tashkent earthquake.

Research conducted in the Tashkent artesian basin made it possible to determine that hydrogeochemical and radiohydrogeological anomalies manifested in changes in the chemical, gas and isotopic composition of groundwater during the tremors shortly before and after the Tashkent earthquake.

Later, similar changes were observed during the earthquakes of Dagestan, Kadamzhai, Aloy, Gazli and

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others. At the same time, along with changes in the gas-chemical composition of groundwater, changes in their level, temperature, flow rate, and layer pressure were observed.

Seismic events can damage the earth's crust and affect the physical and chemical properties of groundwater and geothermal waters. Currently, many researchers are trying to promote the relationship between earthquakes and changes in the physical and chemical properties of groundwater, through field research and scientific research in various ways[7-16]. Extensive research is being conducted in this direction using various methods, including seismological, geophysical, astrophysical, biophysical, hydrogeochemical, and others. The authors note that with the expansion of hydraulic fracturing, geothermal energy development, and the use of underground coal mines, humans are increasing the number of such earthquakes each year, and their impact on groundwater, particularly in water-prone areas, is increasing. should be taken. The researchers conducted their research at the Grimsel landfill in Switzerland, which includes a series of tunnels and boreholes drilled into granite near Lake Raterichsboden. As the team observed the object, the draining and filling of the reservoir caused microearthquakes. Groundwater pulses propagated from the earthquake sites, through the local fault network, and into the tunnels. Observations from tunnel boreholes indicated that earthquakes did not alter groundwater pressure or solute concentrations. However, they found that small earthquakes can temporarily make the groundwater more acidic and lower the PH. The results are the first field evidence of earthquake-induced groundwater acidification, the authors say. Researchers studied this phenomenon in laboratory experiments by crushing and breaking rocks similar to those at Grimsel. These experiments, in which the pH value of the water decreased for several days, showed that the increase in acidity was caused by silanol and silica radicals formed on new mineral surfaces during the concentration of hydrogen ions in the water. Groundwater pH affects many geochemical reactions underground. The new findings, according to the authors, will significantly contribute to the understanding of groundwater chemistry and water-rock interactions.

The purpose of this study is to analyze current topics and key regions of earthquake groundwater impact research in a seismically active region, and to use historical scientific data to gain new insights into international earthquake groundwater impact research trends and directions.

2. Materials and methods

In this review, we focused on gathering regional knowledge from existing studies. The research was conducted using the Scopus database, the most widely used bibliographic online database, covering the period from 1970 to 2024. We used "groundwater" and "earthquakes" as keywords, including specific countries such as China, the Russian Federation, Japan, Turkey, Armenia, India, and Uzbekistan. The analysis was carried out in July 2024. For analysis, we used a CSV file, Microsoft Excel 2021, RIS, VOS viewer and Map chart, each of which performs a specific function in the process of data processing and visualization.

2.1. Eligibility criteria for article selection and review

For the searching process, relevant information, such as keyword “groundwater” and all articles in English, were added to a spreadsheet. Article = (“groundwater”), document type = “article”, timespan = “1970–2024”, Subject area = Environmental Science, Earth and Planetary Sciences, Agricultural and Biological Sciences, Hydrogeology, countries = USA, Japan, China, Armenia, India, Italy, Russian Federation, Uzbekistan and deadline = January 2023. **Figure.1** shows the flow of the selected methodology for the research. During the screening process, the following exclusion criteria were used.

1 only the title and abstract of the article are reported in English, but the rest is in another language

2. articles related to other research areas

3. lack of definition of search terms (stability, sensitivity, resistance).

4. many articles do not have a DOI and the ability to find articles is limited. In general, it was not possible to exclude these articles using the filter options in Scopus.

2.2. Bibliometric analysis

Data obtained in CSV format were uploaded to Excel for bibliometric analysis. Before starting the analysis, the data were thoroughly checked for errors. The reviewed articles were analyzed, and the most relevant ones were identified, along with their corresponding authors – those who created the most articles. The articles from the search were assessed and classified according to various aspects: number of papers per year, document type, top list of papers, top journals, top funding sponsors, distribution by subject categories and journals, and affiliation by country and institution. Finally, the co-authors and co-occurrence of keywords were analyzed to explore the knowledge components and structure of the research domain by identifying clusters of the most common keywords in the literature.

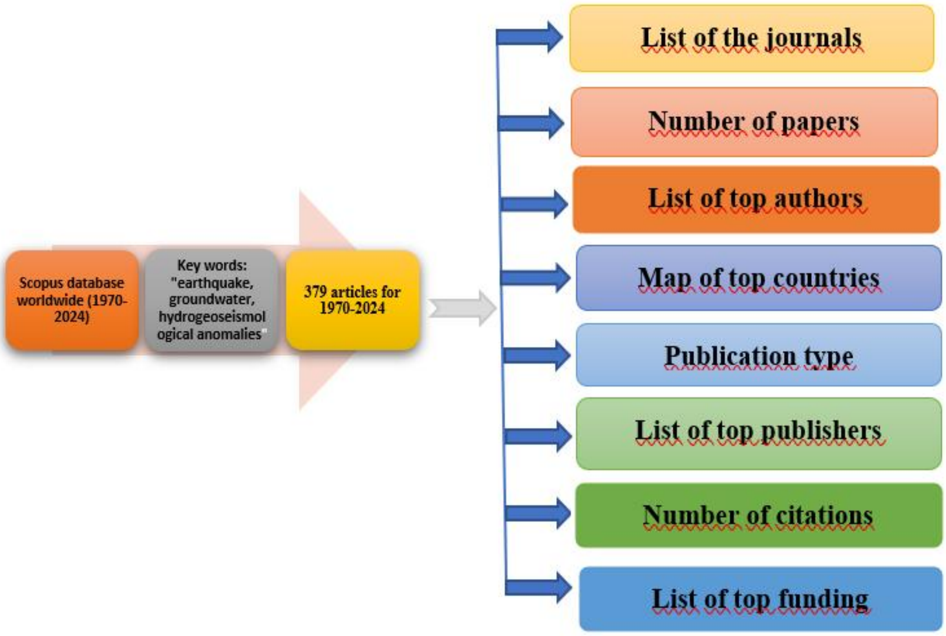

Figure 1. Methodology flowchart for the research.

3. Results and discussion

3.1. Publication trends of observed hydrogeochemical anomalies in groundwater due to earthquakes

In 1970-2024, a total of 379 articles on the problem of hydrogeoseismological anomalies were published in the CIS countries (**Figure.2**). The number of publications increased from 1 to 29 in 1970-2024. **Figure.1** shows that a total of 123 articles were published between 1970 and 2010, increasing from 9 to 29 from 2011 to 2020. In 2021, 24 articles were published. 39 articles were published in 2022-2023. In 2024, 19 articles were published. 2020 has the most publications, accounting for 7.65% of total publications. These published articles provide information on 191 earthquakes (**Table.1**)[17-24]. Of these, 22 earthquakes of M=3.8-8 occurred in Japan in 1976-2016. Anomalies in 12 parameters were recorded in these earthquakes. In Iceland, 7 earthquakes of M=2.7-5.8 from 1978-2013 were considered, in which anomalies were observed in a total of 20 parameters. The largest number of hydrogeoseismological studies were conducted in China, and during 1975-2022, anomalies were observed in 24 parameters during a total of 51 M=3.3-8.1 earthquakes.

Table 1. Conducting hydrogeoseismological research in seismically active regions of the world.

№	State names	Earthquakes	In magnitude	Parameters
1	Japan	17.01.1995	M=7,2	Cl^-, SO_4^{2-}, Rn, ^2H, N_2/Ar
2		16.04.2016	M=7,3	$\delta^{18}O$
3		21.10.2016	M=6,6	$\delta^{18}O$
4		26.05.1983	M=7,7	H_2
5		14.09.1984	M=6,8	H_2
6		06.03.1984	M=7,9	Rn
7		06.02.1987	M=6,4;6,7	Rn
8		14.01.1987	M=7	Rn
9		23.09.1990	M=6,5	level
10		28.07.1976	M=7,6	Cl-, CO_2
11		25.09.2003	M=8	level
12		14.09.1984	M=6,8	H_2, N_2/Ar, He/Ar, CH_4/Ar
13		06.08.1982	M=3,8	H_2
14		24.09.1990	M=6,6	He/Ar
15		11.05.1991	M=3,9	He/Ar
16		01.06.1990	M=6	Rn
17		06.08.1977	M=4,3	He/Ar
18		14.01.1978	M=7	He/Ar, Rn
19		26.05.1983	M=7,7	H_2
20		10.12.1982	M=4,9	CH_4/Ar
21		06.03.1984	M=7,9	Rn
22		06.02.1987	M=6,7	Rn
23	Indonesia	13.06.2018	M=6,0	level
24		15.01.2021	M=6,2	Mn
25	Iceland	16.09.2002	M=5,8	$\delta^{18}O$, δ^2H, B, Ca, K, Li, Mo, Na, Rb, S, Si, Sr, Cl, SO_4, Cu, Zn, Mn, Cr
26		21.10.2012	M=5,5	$\delta^{18}O$, δ^2H, Na, K, Si
27		02.04.2013	M=5,3	$\delta^{18}O$, δ^2H, Na, K, Si
28		03.07.1978	M=2,7	Rn
29		28.8.1978	M=3,4	Rn
30		19.11.1978	M=4,3	Rn
31		15.12.1979	M=4,1	Rn

№	State names	Earthquakes	In magnitude	Parameters
32		29.06.1873	M=6.3	level
33		26.09.1997	M=5,7	level
34		06.04.2009	M=6,3	U, Debit
35		01.04.2017	M=6,0	Rn
36	Italy	23.11.1980	M=6,5	Rn
37		31.12.2019	M=6,5	Rn
38		30.10.2016	M=6	T
39		21.06.2013	M=7	CO_2
40		22.05.2021	M=7,4	T, level, Rn
41		27.6.1976	M=7,8	Rn
42		29.5.1976	M=7,5	Rn
43		15.11.1976	M=7,8	H_2
44		8.01.2022	M=6,9	T, level, Rn
45		26.03.2022	M=6,0	T, level, Rn
46		19.10.1989	M=6,1	H_2
47		14.11.2001	M=7,8	level, T, Rn
48		18.10.1989	M=6,1	level
49		10.01.1998	M=6,1	level
50		12.05.2008	M=8,0	level, K^+, SO_4^{2-}, Na^+, Cl^-, $\delta^{18}O$, δ^2H
51		28.06.1978	M=6,4	T
52		24.01.1981	M=6,9	T
53	China	04.06.1990	M=7,3	T
54		18.07.1969	M=7,4	Rn
55		04.02.1975	M=7,3	Rn, level
56		16.09.1976	M=7,2	Rn
57		21.05.1984	M=6,2	Cl^-
58		24.10.2005	M=6,5	Hg
59		4.07.2006	M=5,1	Hg
60		04.02.1975	M=7,4	F
61		28.07.1976	M=7,8	F
62		28.07.1977	M=6,5	F
63		12.05.2008	M=7.9	Rn
64		22.07.2013	M=6,6	Rn
65		11.11.2012	M=7	Rn
66		20.04.2013	M=7	Rn, Ca, HCO_3, SO_4, Cl, Na

№	State names	Earthquakes	In magnitude	Parameters
67		12.02.2014	M=7,3	Rn
68		25.04.2015	M=8,1	Rn
69		12.05.2015	M=7,5	Rn
70		14.11.2015	M=7,2	Rn
71		21.01.2016	M=6,4	Rn
72		08.08.2017	M=7	Rn
73		11.09.2018	M=5,9	Cs, Rb, V
74		10.03.2011	M=5	T, level, Rn
75		21.09.1999	M=7,6	Rn, level
76		03.02.2022	M=3,3	level, Li, Sc, Ti, Pb
77		10.01.1998	M=6,2	CO_2
78		3.06.2007	M=6,4	Rn, pH, Ca, F, Mg, HCO_3
79		6.12.2021	M=4,7	Na^+,Cl^-,SO_4^{2-}
80		10.06.2021	M=6,0	Na^+,Cl^-,SO_4^{2-}
81		22.12.2022	M=5,0	Na^+,Cl^-,SO_4^{2-}
82		11.09.2018	M=5,9	Cs, Rb, V
83		10.01.2013	M=3,8	T
84		21.04.2013	M=7.0	Na^+,Cl^-,SO_4^{2-} , $\delta^{18}O$, δ^2H
85		22.11.2014	M=6.3	Na^+,Cl^-,SO_4^2
86		21.06.2003	M=6,0	Ca^{2+}, Mg^{2+}, HCO_3^-
87		24.03.2011	M=6.9	Ca^{2+}, Mg^{2+}, HCO_3^-
88		8.09.2018	M=5.7	Ca^{2+}, Mg^{2+}, HCO_3^-
89		18.07.1969	M=7,4	Rn
90		16.09.1976	M=7,2	Rn
91		15.11.2017	M=5,5	level, Rn, ^{18}O, ^2H
92	Korea	12.09.2016	M=5,8	level
93		14.03.2005	M=5,1	Cl^-, SO_4^{2-},F^-, $\delta^{18}O$, level
94		20.10.1991	M=7	Rn
95		12.1.1993	M=4,4	Rn
96		29.3.1999	M=6,8	Rn, He
97	India	26.01.2001	M=7,6	level
98		11.06.2007	M=5,1	Rn
99		12.12.2009	M=5.1	level, Rn
100		14.11.2009	M=4,7	Rn
101		15.03.2008	M=6,3	He, Rn, CH_4

№	State names	Earthquakes	In magnitude	Parameters
102		26.10.2015	M=7,7	Rn
103		27.03.2021	M=5,0	Li^+,Cl^-, F^-, Ca^{2+},Na^+, B, Be
104		5.04.2021	M=5,1	Li^+,Cl^-, F^-, Ca^{2+},Na^+, B, Be
105		7.07.2021	M=5,2	Li^+,Cl^-, F^-, Ca^{2+},Na^+, B, Be
106		25.02.2021	M=3,6	Li^+,Cl^-, F^-, Ca^{2+},Na^+, B, Be
107		19.05.2021	M=3,2	Li^+,Cl^-, F^-, Ca^{2+},Na^+, B, Be
108		28.04.2021	M=6,4	Li^+,Cl^-, F^-, Ca^{2+},Na^+, B, Be
109		2.03.1992	M=7,1	Cl^-, Ca^{2+},Na^+, HCO_3^- , CO_2, H_2
110		10.06.1987	M=5	Na^+, Cl^-, HCO_3^-
111		03.02.1992	M=7,1	Na^+, Cl^-, HCO_3^-, Ca^{2+},SO_4^{2-}, CO_2, CH_4
112		8.07.1993	M=7,3	HCO_3^-,Ca^{2+}, SO_4^{2-}, Na^+
113		01.01.1996	M=6,9	Cl^-, Na^+, HCO_3^-, SO_4^{2-},
114		21.06.1996	M=7,1	N_2, Ar, CO_2, CH_4
115	Russia	5.12.1997	Ks=15,5	Cl^-, Na^+, HCO_3^-, level
116		8.10.2001	Ks=14,1	Cl^-
117		5.08.2002	Ks=13,5	Cl^-, Na^+
118		24.11.1971		Debit, T^0
119		30.01.2016	M=7,2	level, Rn
120		27.08.2008	M=6,3	He
121		30.10.1983	M=6.8	He
122		07.12.1988	M=7	level, HCO_3^- , pH, Cl^- , Rn
123		20.06.1990	M=7	He, Rn, HCO_3, pH, level, Cl
124		29.04.1991	M=7.1	He, Rn
125		13.03.1992	M=6.9	He
126		24.10.1992	M=6.4	He, level, Rn
127		10.12.1992	M=5.0	level
128		19.02.1993	M=3.8	level, Rn , He
129	Armenia	18.05.1994	M=4.2	Rn, level, He
130		09.06.1996	M=4.1	Cl^-, level, Rn, He, pH
131		28.02.1997	M=6.7	level, Rn, P
132		01.03.1997	M=3.7	Rn, pH,
133		18.07.1997	M=4.4	HCO_3^-, level, Rn, He
134		15.01.1999	M=4.3	Rn, level
135		17.08.1999	M=7.4	Rn, Debit, level, T^0, pH, He
136		03.02.2002	M=6.2	level, Debit, T^0, Rn, Rn

№	State names	Earthquakes	In magnitude	Parameters
137		30.10.2020	M=6,6	T^0C, level, EC
138		02.12.2013 06:11:25	M=3.4	T^0C, pH, EC, Na^+, Cl^-, SO_4^{2-}
139		08.04.2014 23:08:36	M=3.7	T^0C, pH, EC, Na^+, Cl^-, SO_4^{2-}
140		24.04.2014 18:16:03	M=3.2	T^0C, pH, EC, Na^+, Cl^-, SO_4^{2-}
141		24.05.2014 09:31:18	M=5.1	T^0C, pH, EC, Na^+, Cl^-, SO_4^{2-}
142		24.05.2014 09:33:48	M=4.0	T^0C, pH, EC, Na^+, Cl^-, SO_4^{2-}
143		24.05.2014 09:34:16	M=4.1	T^0C, pH, EC, Na^+, Cl^-, SO_4^{2-}
144	Turkey	24.05.2014 10:35:01	M=4.2	T^0C, pH, EC, Na^+, Cl^-, SO_4^{2-}
145		24.05.2014 12:25:00	M=6.5	T^0C, pH, EC, Na^+, Cl^-, SO_4^{2-}
146		25.05.2014 11:38:38	M=4.9	T^0C, pH, EC, Na^+, Cl^-, SO_4^{2-}
147		25.05.2014 11:47:55	M=4.5	T^0C, pH, EC, Na^+, Cl^-, SO_4^{2-}
148		28.05.2014 03:59:51	M=4.5	T^0C, pH, EC, Na^+, Cl^-, SO_4^{2-}
149		23.07.2014 14:14:33	M=3.0	T^0C, pH, Rn, EC, Na^+, Cl^-, SO_4^{2-}
150		06.02.2023	M=7,7;7,6	EC, Ca^{2+}, Mg^{2+}, K^+, Na^+, Cl^-, SO_4^{2-}
151		23.10.2011	M=7,2	$^3He/^4He$, ^{13}C
152		21.09.1999	M=7.3	Cl^-, SO_4^{2-}, level
153		18.10.1980	M=5,8	Rn
154		14.5.1981	M=5,2	Rn
155		21.6.1981	M=4,6	Rn
156		31.10.1982	M=5,3	Rn
157	Taiwan	18.04.2021	M=6,2	Na^+, Cl^-, SO_4^{2-}
158		26.12.2006	M=7,2	Ca^{2+}, Cl^-, HCO_3^-
158		12.05.2018	M=5,5	T
160		19.03.2014	M=5,2	Rn, CO_2, CH_4, $^3He/^4He$, ^2H, ^{18}O, Ar, Cl
161		1.01.1979	M=5	Rn
162		30.06.1979	M=4,8	Rn
163	USA	17.3.1976	M=4,3	Rn
164		19.1.1977	M=4	Rn
165		15.12.1977	M=4	Rn

№	State names	Earthquakes	In magnitude	Parameters
166		8.4.1909	M=6,7	H_2
167		29.8.1978	M=4,2	Rn
168		1.1.1979	M=4,6	Rn
169		8.4.1985	M=5,6	Rn
170		15.10.1979	M=6,6	Rn
171		15.5.1983	M=4,2	Rn
172		30.6.1979	M=4,8	Rn,He
173		17.10.1989	M=7,1	He
174		6.8.1979	M=5,9	He
175		24.1.1980	M=5,5	He
176		13.4.1980	M=4,9	He
177		13.4.1980	M=4,8	^2H
178		10.7.1979	M=4,8	He, CH_4, Ar, N_2,
179		14.2.1983	M=6,3	Rn
180		26.06.2016	M=5,3	pH, T °C, CO_2, HCO_3, Ca, Cl, Mg
181	Kyrgyzstan	25.3.1978	M=6,6	level
182		2.11.1978	M=6,8	level
183		26.4.1966	M=5,3	Rn
184		24.3.1967	M=4	Rn
185		20.6.1967	M=3,5	Rn
186		22.7.1967	M=3.5	Rn
187	Uzbekistan	9.11.1967	M=3	Rn
188		17.11.1967	M=3.3	Rn
189		13.2.1973	M=4,7	Rn
190		17.5.1976	M=7,3	Rn, level
191		24.05.2013	M=5,3	He, H_2, N_2, O_2, CO_2, HCO_3, Cl, pH, Eh

Table.1*(continued)*

According to the results, changes in 40 parameters were observed in 191 earthquakes. The total anomaly of Rn gas, which is a radioactive inert gas, was 18%. Changes in the level of groundwater - 8%, sodium and chlorine ions - 7%, sulfate ions - 6%, helium gas - 5%, calcium ions - 3%, changes in groundwater temperature - 6%, electrical conductivity anomalies of groundwater 3% and the remaining parameters were found in percentages of 2% (**Figure.3**) [25-34].

In addition, our research shows that out of 379 articles, the most 344 (90.76%) are research papers, followed by 25 (6.59%) conference proceedings, 10 (2.64%) organized books (**Figure.4**).

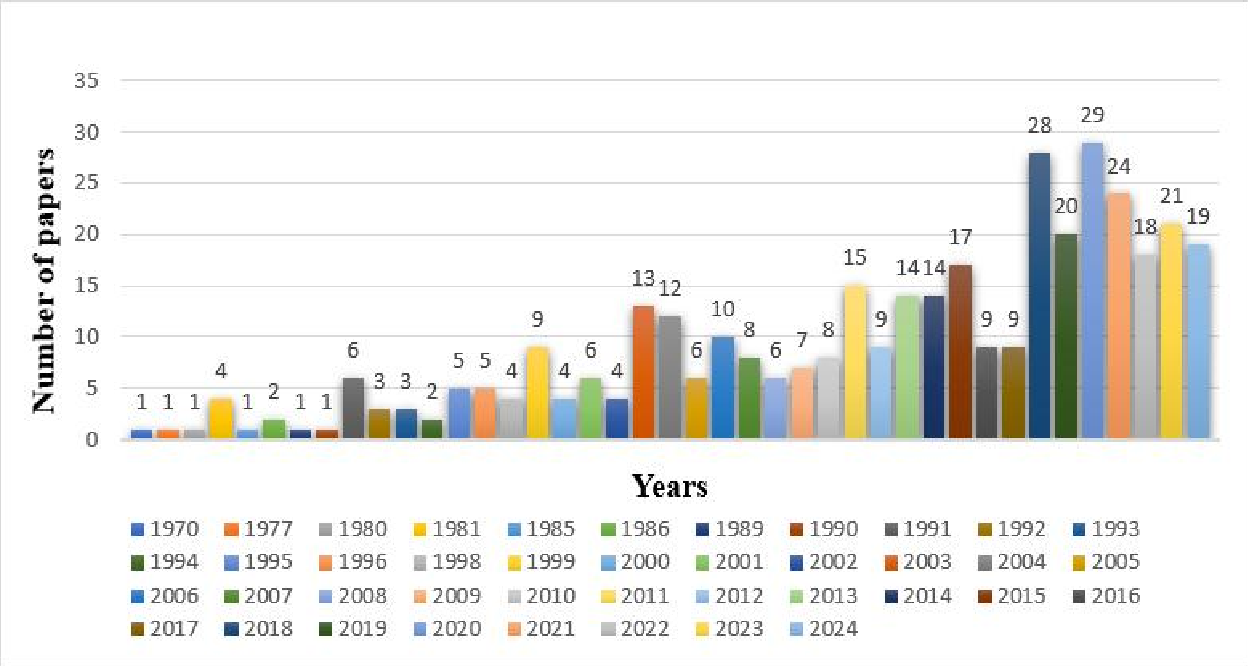

Figure 2. Number of articles on hydrogeoseismological anomalies in the CIS countries from 1970 to 2024.

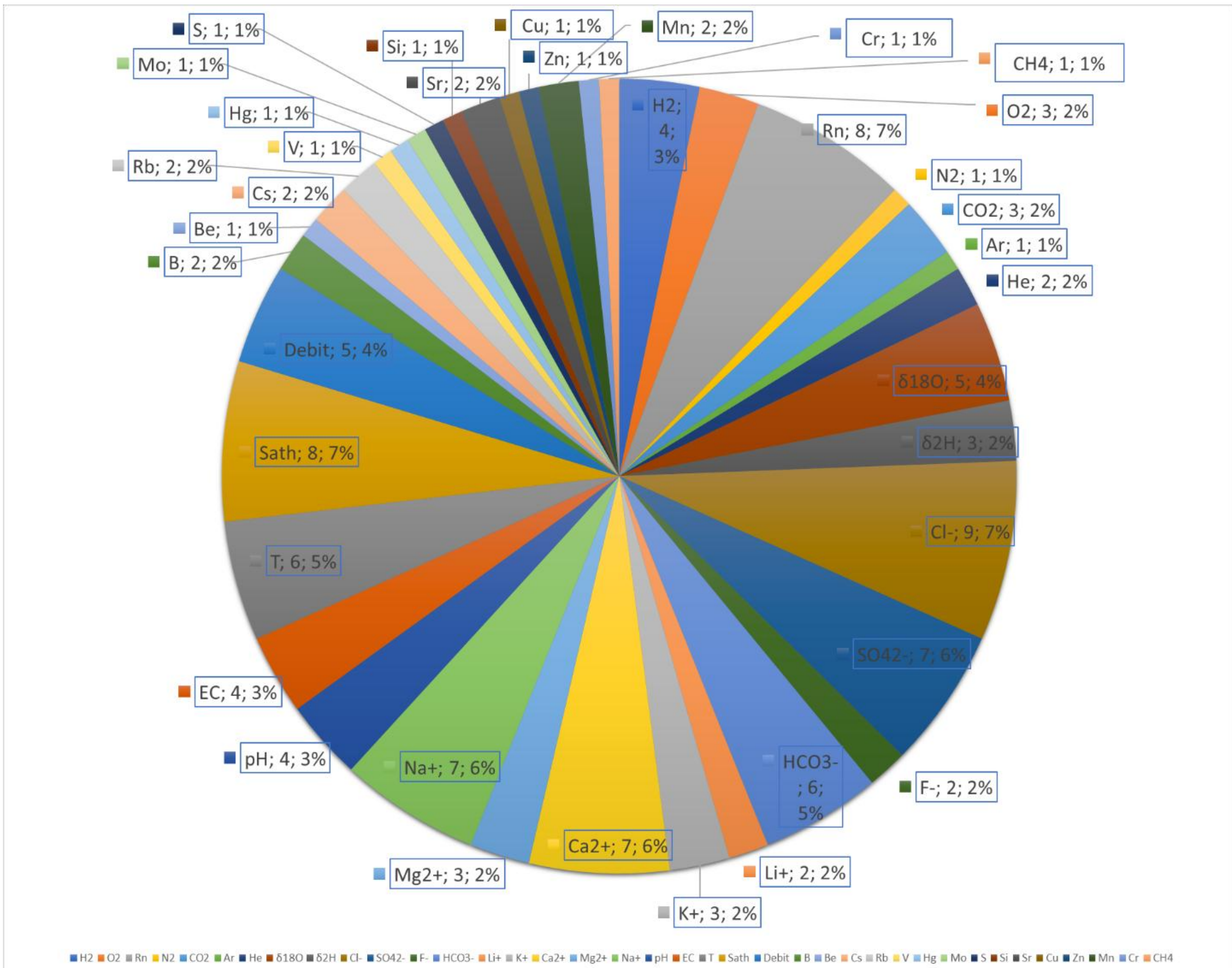

Figure 3. Expression of hydrogeoseismological parameters in quantitative values in earthquakes observed from 1970 to 2024

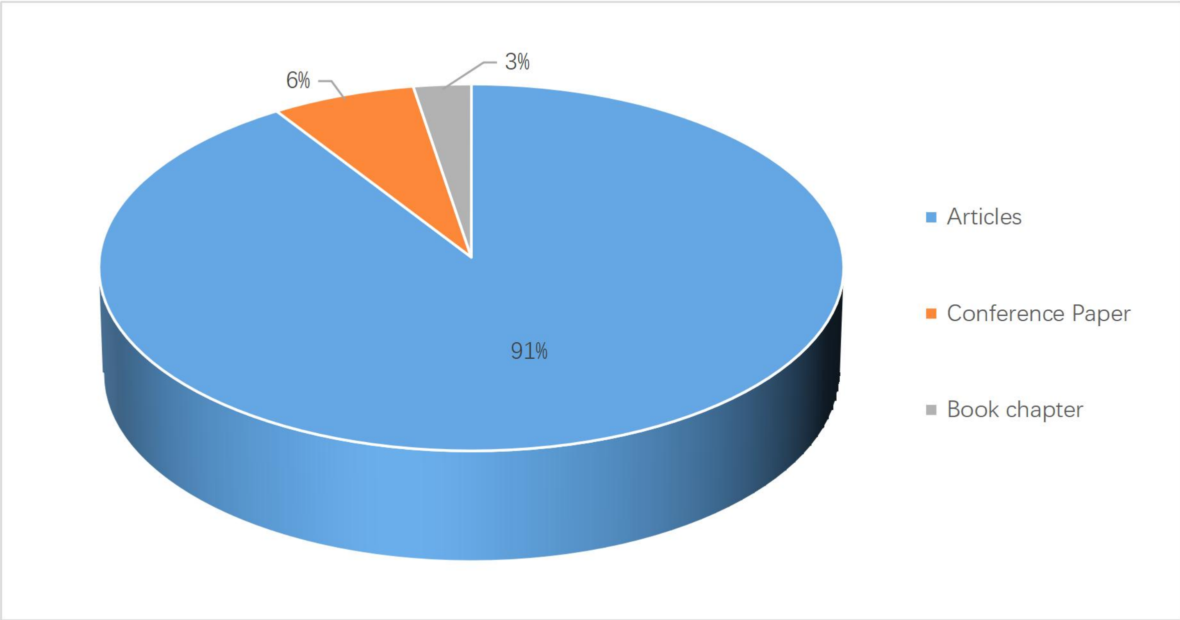

Figure 4. Types of publications on hydrogeoseismological anomalies.

3.2. Journals of hydrogeoseismological anomalies in earthquakes

Scientists from different parts of the world publish their research in different journals. Based on scientific communication models, a general distribution of products was made for 90 journals published in many countries. Of these 379 articles, 93 (24.5%) were published in 5 journals, and the remaining 75.5% were published in other journals. **Table.1** lists the names of 65 journals in which at least 2 or more articles were published during the above-mentioned period.

Table 2. List of journals published by year on hydrogeismological anomalies in groundwater caused by earthquakes.

Scopus source title	Number	Scopus source title	Number
Journal of Hydrology	24	Radiation measurements	7
Pure and applied geophysics	17	International journal of environmental research and public health	2
News of The National Academy of Sciences of The Republic of Kazakhstan Series of Geology and Technical Sciences	3	Journal of radioanalytical and nuclear chemistry	8
AGU	4	Minerals	2
Geochemical journal	4	Geodesy and Geodynamics	2
Geofluids	3	Hydrogeology journal	3
Tectonophysics	9	Geohysics	2
Journal of Asian Earth Sciences	5	SCIENCE	2
Chemical Geology	4	GEOPHYSICAL	5

Scopus source title	**Number**	**Scopus source title**	**Number**
		RESEARCH LETTERS	
Applied Geochemistry	4	JOURNAL OF PHYSICS OF THE EARTH	2
Solid Earth Geophsics	3	Earthquake scierce	2
Spinger Link	9	ACTA GEOPHYSICA	5
Physics and Chemistry of the Earth	2	Applied radiation and isotopes	
Natural Hazards and Earth System Sciences	14	Environmental earth sciences	3
Journal of Volcanology and Geothermal	2	Radon and thoron in the human environment	2
EARTH AND PLANETARY SCIENCE LETTERS	5		
Geothermics	2	Journal of geodynamics	2
GEOCHEMISTRY-EXPLORATION ENVIRONMENT ANALYSIS	4	Earth plants and space	2
GEOLOGY	2	Arabian journal of geosciencen	2
Science of The Total Environment	2	Applied Geochemistry	7
ACTA GEOPHYSICA	5	Environmental geology	2
Journal of geochemical exploration	2	Bollettino di geogfisica teorica ed applicata	2
FRONTIERS IN EARTH SCIENCE	9	HydroResearch	2
SCIENTIFIC WORLD JOURNAL	2	Journal of seismology	4
Journal of Plant Nutrition	2	Geophysical journal international	4
Geosciences	3	Nuclear tracks and radiation measurements	4
Enginering Geology	2	Groundwater for Sustainable Developments	2
Scientific reports	6	Radiation measurements	6
Journal of environmental radioactivity	2	Russion Geology and Geophysics	2
Chemosphere	2	Journal of Molecular Liquids	2
Water	8	Terrestrial atmosphere and oceanic sciences	2
Journal of geophysical research solid earth	2	Turkish journal of eart sciences	2
Hydrological processes	2	Geochemistry international	2

Table.2*(Continued)*

3.3. Authors and their respective countries

Our research showed that 790 authors from 14 countries conducted research on hydrogeismological anomalies caused by groundwater earthquakes during 1970-2024. **Figure.5** lists ten authors who published four or more articles. Among them Biagi P.F. Dominated in 8 editions, followed by Wang, B.P. 7, Martinelli, G. 6, Chen, H.H., Igarashi, G., Alam, A., Inan, S., Kopylova, G., Kuo, T., Sano, Y. each have 4 scientific articles [35-45].

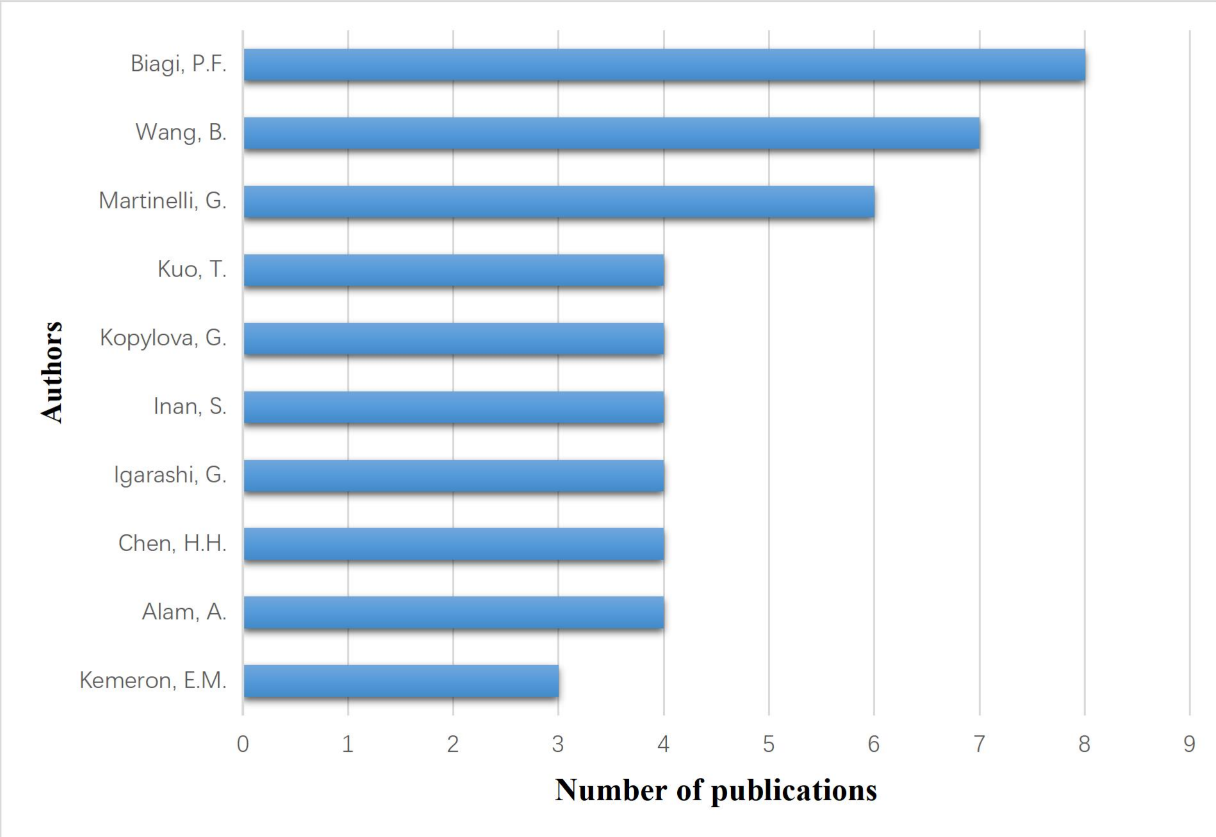

Figure 5. List of best published authors on hydroseismological anomalies in groundwater caused by earthquakes.

3.4. List of leading countries in terms of hydro-seismological anomalies

Figure.7 shows the top five countries producing groundwater hydroseismological anomalies during earthquakes from 1970 to 2024. Among them, China (78; 20,58%) is the leader in publications, Japan (46; 12%), Turkey (46; 12%), India (22; 7.5%) and the Russian Federation (18; 6.2%).

3.5. Co-authors and keywords on hydrogeseismological anomalies.

Using the VOSviewer program, co-authorship, co-occurrence of key words, citations, bibliographic combinations and co-citation maps can be created based on bibliographic data. Supported file formats include .txt, ris and .csv from databases such as Scopus (Samir Kumar Jalal, 2019). The file was imported into VOSviewer and a co-authorship and keyword co-occurrence map (shown in **Figure.7,8**) was generated using the software. As a result of co-authorship analysis, a network of 1053 authors emerged.

As a result of the analysis, 976 keywords were found. After removing less relevant and infrequent keywords (by default, at least five occurrences of a keyword are selected to boost co-occurring results), 20 items were identified. Based on the overall link strength, each resulting keyword is compared to a single node, creating a network map of all keywords. **Figure.7** shows the network map of the top 20 authors with keywords. The size of the node reflects the importance of the keyword.

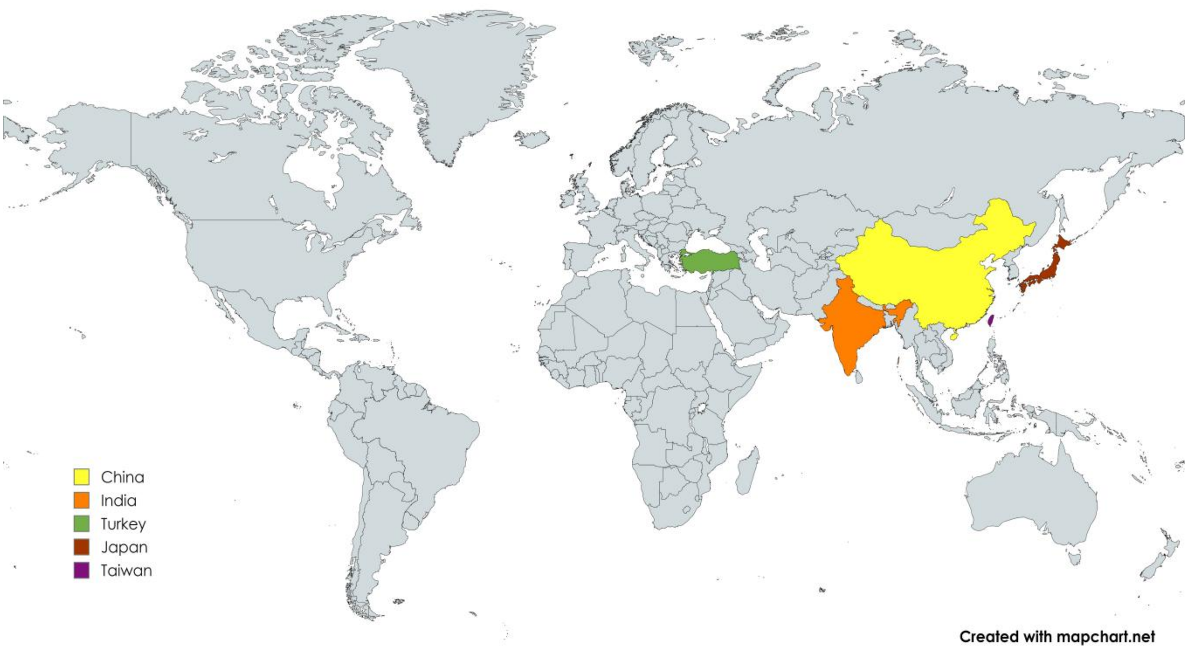

Figure 6. List of leading countries in terms of hydrogeoseismological anomalies.

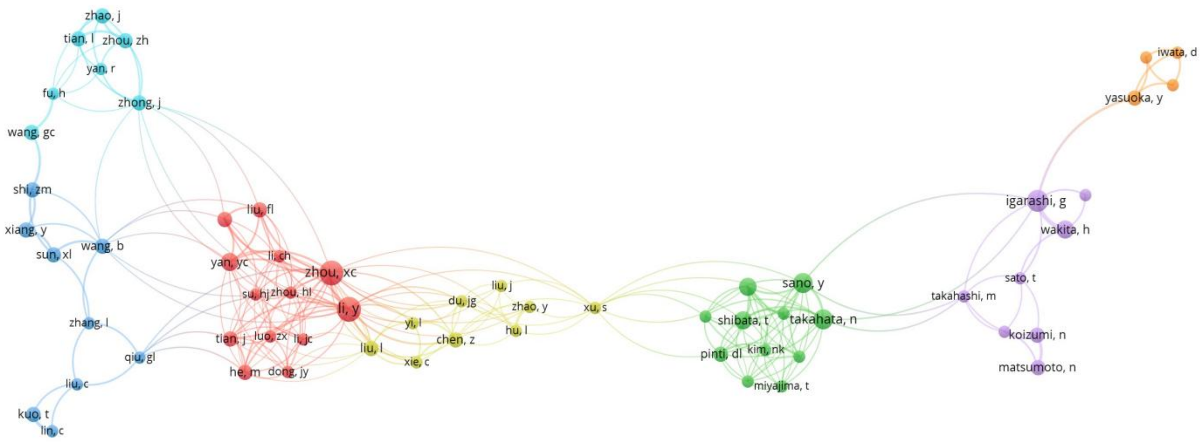

Figure 7. Network map of top affiliates based on total link strength.

4. Discussion

Between 1970 and 2002, on average, one to ten articles were published. In 2003, it increased to 13. From 2003 to 2010, a total of 66 articles were published. From 2011 to 2019, the average number of articles is 9-28. In 2020, this indicator increased to 29 and made up 7.65% of the total articles. 18, 21, 19 articles were published between 2022 and 2024, respectively. According to the results, changes in 40 parameters were observed in 191 earthquakes. The total anomaly of Rn gas, which is a radioactive inert gas, was 18%.

Changes in the level of groundwater - 8%, sodium and chlorine ions - 7%, sulfate ions - 6%, helium gas - 5%, calcium ions - 3%, changes in groundwater temperature - 6%, electrical conductivity anomalies of groundwater 3% and the rest of the parameters are less than 2%.

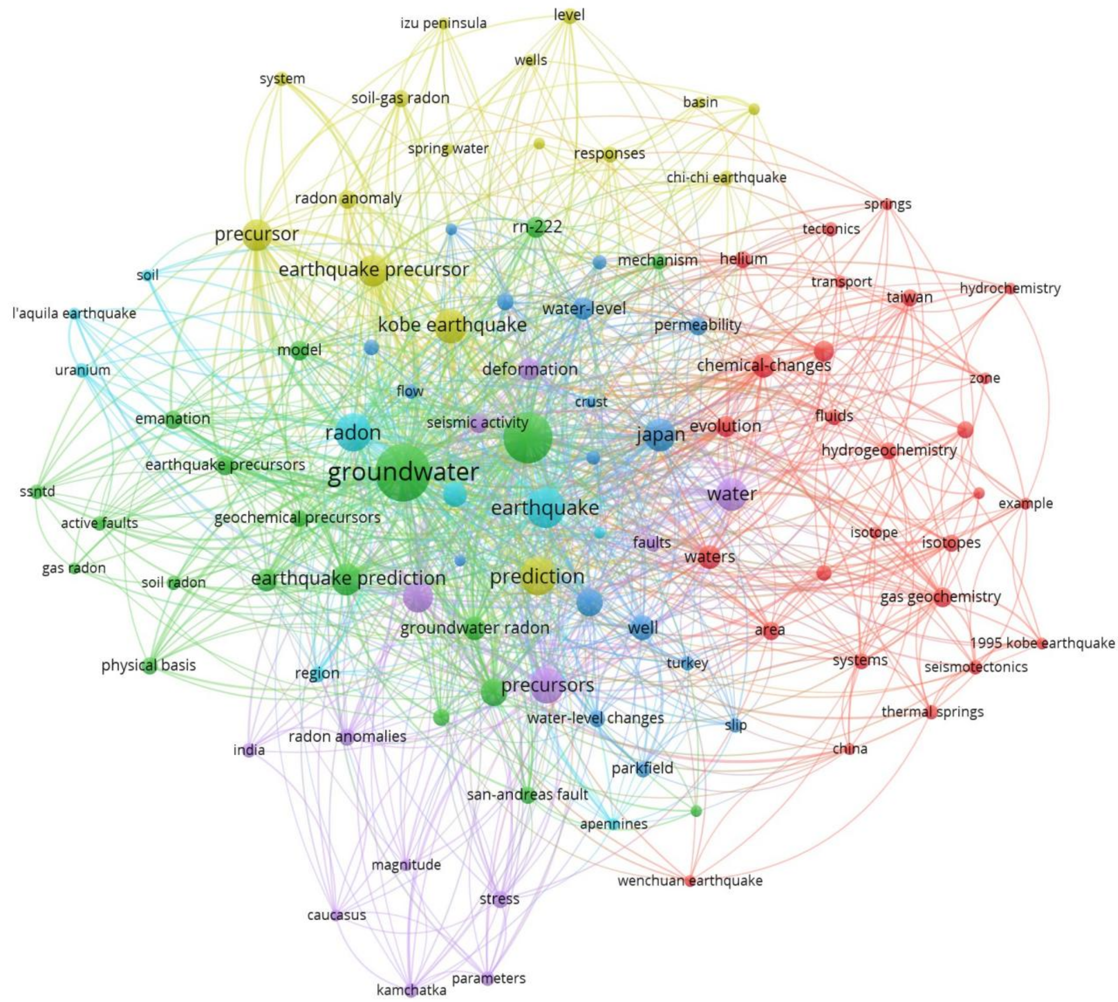

Figure 8. Network map of top keywords based on total link strength.

5. Conclusions

This tudy offers a comprehensive bibliometric statistical analysis of the literature on hydrogeoseismological anomalies observed in groundwater as a result of earthquakes in the CIS countries in the period 1970-2024. According to the results, changes in 40 parameters were observed in 191 earthquakes. The total anomaly of Rn gas, which is a radioactive inert gas, was 18%. Changes in the level of groundwater - 8%, sodium and chlorine ions - 7%, sulfate ions - 6%, helium gas - 5%, calcium ions - 3%, changes in groundwater temperature - 6%, electrical conductivity anomalies of groundwater 3% and the remaining parameters were found in 2% percent. The results showed a significant increase in the number of publications over the past 14 years. Basically, scientists preferred to publish their findings in journals in the format of academic scientific articles (91%). The largest number of hydrogeoseismological studies were conducted in China, and during 1975-2022, anomalies were observed in 24 parameters during a total of 51 M=3.3-8.1 earthquakes.

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