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Review article

Groundwater in the commonwealth of independent states: A bibliometric analysis of scopus-based papers from 1972 to 2023, emphasizing the significance of drainage

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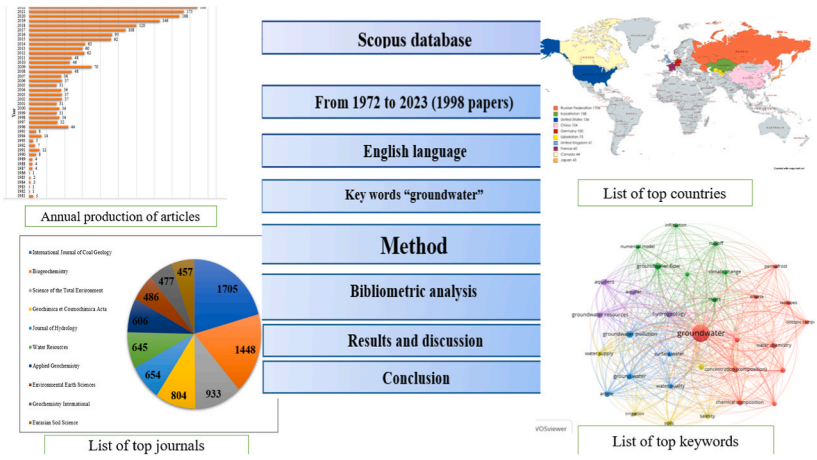
HIGHLIGHTS

- CIS based groundwater studies in Scopus publications for 51 years.
- Bibliometric studies aid in analyzing groundwater research trends and patterns.
- Rising of groundwater level in CIS countries due to poor drainage system control.
- Groundwater related research enhances scientific discourse in CIS countries.

GRAPHICAL ABSTRACT



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ABSTRACT

Groundwater is increasingly recognized as a vital natural resource for industrial and residential water supply, as well as for irrigated agriculture. Research on groundwater quality in agricultural areas has become particularly relevant in this field. It is a crucial source of irrigation water in many arid and agricultural regions, including the Commonwealth of Independent States (CIS) countries. This paper presents a comprehensive review to understand the research trends in this area. We aim to analyze the scientific output and publications addressing groundwater in CIS countries from 1972 to 2023. For this purpose, we collected, reviewed, and analyzed 1998

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Review
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publications that met our selection criteria in the Scopus database during this period. Our bibliometric analysis revealed that all articles were published in English, with the highest number of publications originating from the Russian Federation, followed by Kazakhstan, the United States of America, China, Germany, Uzbekistan, the United Kingdom, France, Canada, and Japan. Notably, our study shows that the majority of papers were research articles (95.69%), followed by review papers (2%), while only 2.31% were other document types such as conference proceedings, editorials, errata, notes, short surveys, and retracted papers. The analysis underscores the need for international research on groundwater to broaden scientific discourse on this topic. Additionally, it highlights the importance of long-term, continuous research and the sustainable development of groundwater concepts for the integration of future agriculture and groundwater management. This study may pave the way for new trends in agricultural development, focusing on irrigation efficiency, wastewater reuse, mining, treatment, and the impact of climate change within a sustainable, circular economy framework.

1. Introduction

Groundwater is one of the most important natural resources, as evidenced by its increasing significance in many countries worldwide in recent decades (Alikhanov et al., 2021; Mkilima et al., 2022). The groundwater supply is a reliable source of water for many production activities throughout the world, including irrigation (Zektser and Dzhamalov 1981). This phenomenon is also due to the fact that the world's population is increasing and putting more pressure on the groundwater resources (Charzyński et al., 2022). The main conditions and factors considered in the study of groundwater are the effect of groundwater with a particular focus on the importance of drainage in CIS countries (Abduraimova et al., 2021). It is also worth noting that irrigation is the main direction of crop production in agriculture regions (Jalankuzov et al., 2013). At the same time, if the groundwater level is not controlled by drainage, it will have a negative effect on the soil properties (Kannazarova, et al., 2021). Groundwater depth is important factor on the soil properties (soil bulk density) and soil pH (Zhang et al., 2018). Unfortunately, in many CIS countries, the operation and control of drainage systems are often insufficient (Ayars et al., 2006). Therefore, it is important highlighting the need for proper maintenance of these systems for effective agricultural land use (Kannazarova and Muratov 2022).

Our literature review covers several articles on the significance of groundwater in various CIS countries. These include studies on the management of groundwater resources in the Russian Federation (Ivanovich-Pykhtin et al., 2019), drainage reclamation in Belarus (Galkin et al., 2022), hydrogeological conditions of Azerbaijan (Gulmammadov et al., 2022), groundwater monitoring in Moldova (Nastasiuc et al., 2016), current irrigation system management features in Azerbaijan Republic (Oglu Rzayev 2007), groundwater residence time (Schubert et al., 2021) and climate change impact on water resources and crop production in Armenia (Melkonyan 2015), assessment of groundwater safety surrounding contaminated water storage in Kazakhstan (Radelyuk et al., 2021), hydrologic control of groundwater in Kyrgyzstan (Hill et al., 2017), chemical composition and parameters of groundwater in Tajikistan (Kireeva et al., 2020) and typology of groundwater use regulations in agriculture of Uzbekistan (Knorr et al., 2022).

Global groundwater resources are key to sustainable development (Ivushkin et al., 2019). Managing the challenges of over-exploitation and pollution of these resources is a complex task (Qureshi et al., 2011). For this reason, it is necessary and useful to share information and experience on groundwater production management worldwide. Achieving a sustainable status for groundwater entails ensuring no depletion of existing resources and meeting environmental quality objectives for groundwater-dependent surface waters (Sunkari et al., 2022). Monitoring and evaluation of different pollution sources is required for ensuring the safety and security in water resource and environmental protection (Liu et al., 2012). The importance of providing meltwater to surface and groundwater will increase future water impacts throughout the region (Barandun et al., 2020). Given the uncertain buffer provided by groundwater reserves, reliance on groundwater creates additional water vulnerability and risk, especially given the dependence on agriculture for human livelihoods (Juliev et al., 2022) and the impact of climate change on the quality and quantity of groundwater (Nanekely et al., 2023).

Drainage technology has played an important role in the implementation of sustainable agriculture (Zegeye et al., 2021). Drainage systems are of great importance in the CIS countries, which have the largest agricultural output in the world (Kopecký et al., 2013; Respondek 2019). However, in some areas, drainage systems are still in poor condition (Murugappan et al., 2017). It was found that some of the CIS countries have fields with high salinity (Egamberdieva et al., 2010). In order to control the ground water, a drainage system should be used extensively across the fields (Arifjanov et al., 2019). The right choice of drainage parameters during design will allow for minimization of salt fluxes between the crop root zone and groundwater, and between drained lands and receiving water bodies (Dukhovny et al., 2018a). However, drainage design must also take the irrigation system and water management practices into consideration, in order to achieve the optimum water and salt balance in the crop root zone, and also to minimize the amount of salt being mobilized and entering receiving water bodies.

Bibliometric analysis identifies cognitive structures and intellectual relationships by analyzing the performance of documents, authors, countries, journals, and institutions (Maassen 2016). This study aims to provide systematic methods for acquiring transparent bibliographic information related to a specific field of study (Sawassi and Khadra 2021) and to identify topics that the scientific community deems relevant to social, economic, and environmental sustainability (Durán-Sánchez et al., 2020). Furthermore, bibliometrics has contributed to various academic fields such as Earth sciences (delRío-Rama et al., 2020), sustainability (Pizzi et al., 2020), environment (de Sousa 2021), engineering (Cancino et al., 2017) and industry (Mei et al., 2021).

Bibliometric studies are beneficial analytical tools for gaining a deeper understanding of research patterns (e.g., in journals, authors, countries) and characteristics in the groundwater research area (Zhang et al., 2010). Agriculture and groundwater related publications have covered various aspects, including the evolution of groundwater quality assessment in urban areas (Bose et al., 2023) current status and future challenges of groundwater (Xiong et al., 2022), trend on groundwater research (Gyanendra et al., 2022), agricultural mechanization (Xaliqulov et al., 2023), marginal lands characteristics (Jumaniyazov et al., 2023) and development of groundwater salinization research in both coastal and inland areas (Yang et al., 2022).

The purpose of this study is to analyze current topics and key regions in the Commonwealth of Independent States countries in groundwater research and to use historical scientometric data to gain new insights into trends and areas of emphasis in international groundwater research.

2. Materials and methods

In this review, we focused on gathering regional knowledge from existing research. The research was conducted using the Scopus database, the most widely utilized bibliographic online database, for the period from 1972 to 2023. We used 'groundwater' and 'CIS countries' as keywords, including specific countries such as the Russian Federation,

Belarus, Azerbaijan, Moldova, Armenia, Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan. The analysis was performed in January 2023. We identified a total of 1998 publications from CIS countries for further analysis on groundwater issues. For the analysis, we utilized a CSV file, Microsoft Excel 2021, RIS, VOS viewer, and Map chart, each serving a specific function in the data processing and visualization process.

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 = "1972–2023", Subject area = Environmental Science, Earth and Planetary Sciences, Agricultural and Biological Sciences, Engineering, countries = Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russian Federation, Tajikistan, Uzbekistan and deadline = January 2023. Fig. 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. An example of author dominance is shown by Pozdniakov, S.P., with 32 articles (Pozdniakov et al., 2022). 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.

3. Results and discussion

3.1. Publication trend on groundwater in CIS countries

In many arid and agricultural regions, the relationship between groundwater and irrigation water holds a wide range of scientific implications. A total of 1998 papers were published between 1972 and 2023 on groundwater issues in CIS countries (Fig. 2).

In this review, the scientific articles are categorized into three developmental periods: the introduction phase (1972–1995), a period of slight growth (1996–2014), and a period of stable growth (2015–2023).

- Introduction Period: This initial period comprises 87 publications, representing 4.35% of the total. The results indicate that interest in the theme of groundwater in agricultural lands began with a focus on the environmental problem-solution relationship. This includes studies on forecasting changes in water resources (Novikov and Goncharova 1981), groundwater discharge into lakes (Zekster 1995), groundwater fluxes in the global hydrologic cycle (Zektser and Loaiciga 1993a), system modelling ground waters in problems of hydrology (Che Nordin et al., 2021).
- Slight Growth Period: This period includes 817 documents, accounting for 40.89% of the total. It marks an increased scientific interest in this field of research. The data highlight the importance of drainage in groundwater ecosystems and related environments. Key areas of focus include regional nitrogen budgets and riverine fluxes in drainages (Howarth et al., 1996a), soil properties in the drained forest bogs (Efremova et al., 2006), issues related to drained peatlands and their resolution (Zaidel'man 2011), and drainage in high-latitude permafrost-dominated areas (Bagard et al., 2011).
- Stable Growth Period: This final period signifies a key phase of exponential growth, encompassing 1094 documents, which is 54.75% of the total. The year 2022 saw the highest number of publications within this period, with 188 documents, followed by 2021 with 173, indicating consistent growth in the field (Fig. 2). This period marked a strengthening of research in this academic area, covering various topics such as radioactively contaminated drainage water (Bobrov et al., 2015), evaluation of acid drainage (Ryzhenko et al., 2016), control of drainage to improve water management

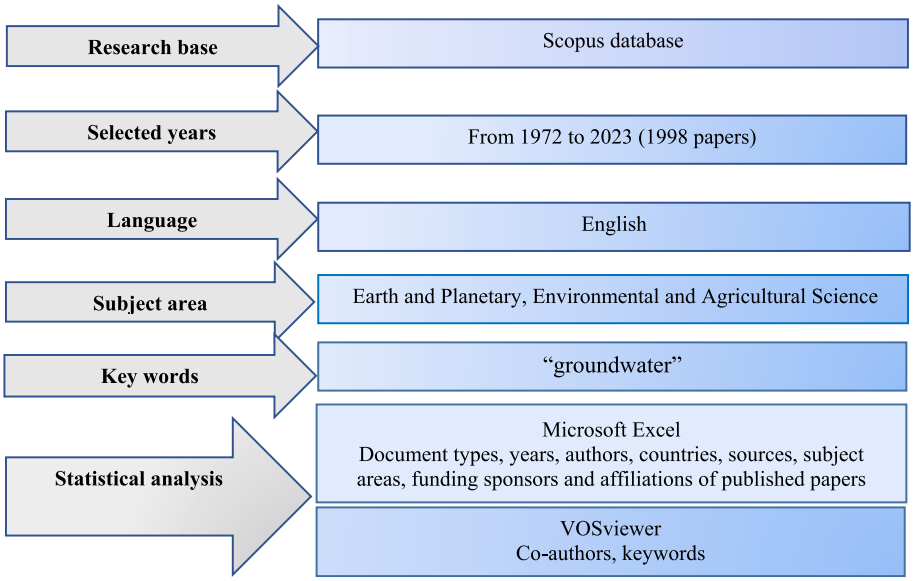

Fig. 1. Methodology flowchart for the research.

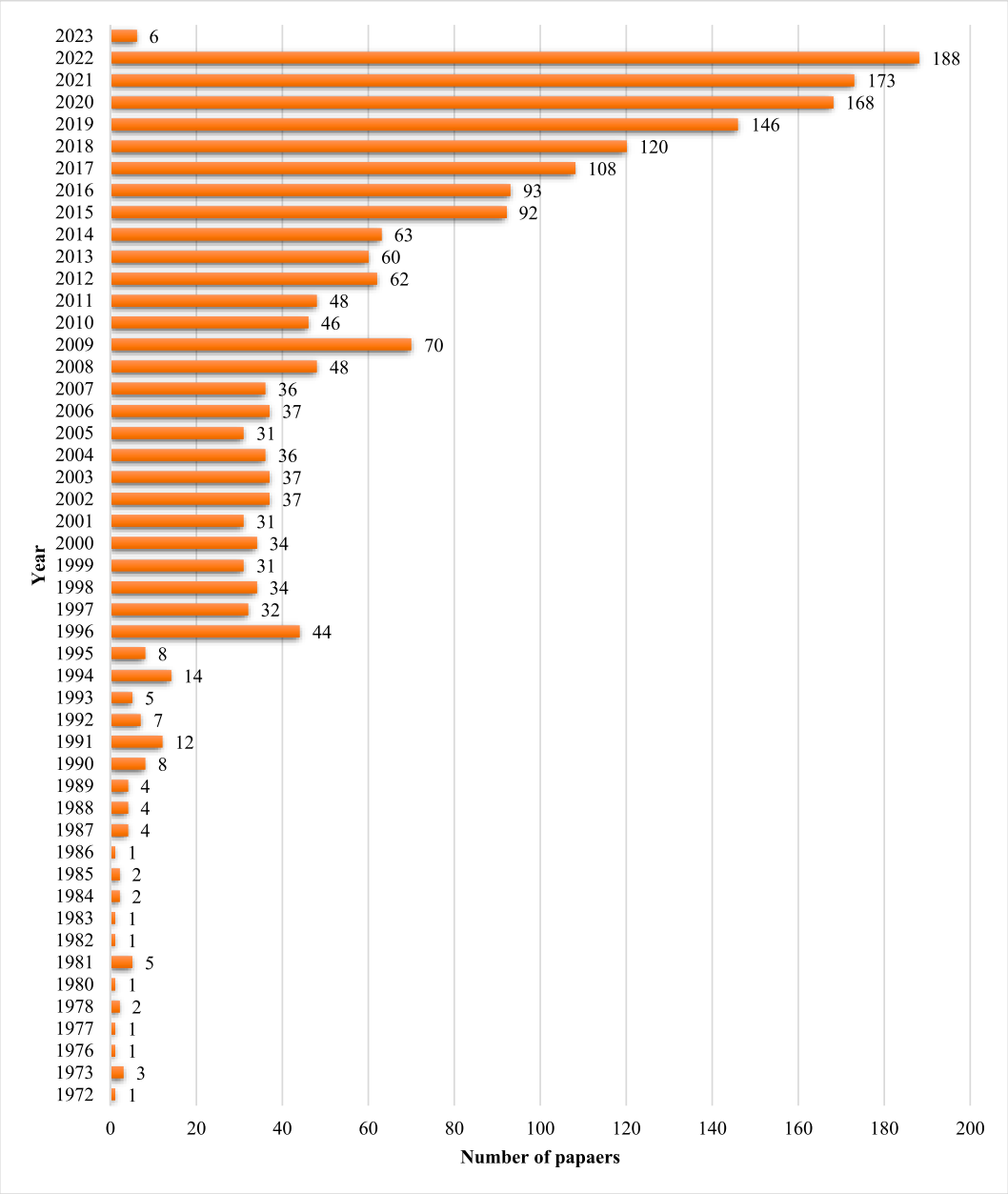

Fig. 2. Annual production of articles on groundwater during the period 1972–2023 in CIS countries.

(Dukhovny et al., 2018b), and models for groundwater level management in drainage systems (Arifjanov et al., 2022a).

Moreover, our study reveals that out of 1998 papers, the largest number, 1912 (95.69%), were research articles. This is followed by 47 review papers, and 31 in conference proceedings. Additionally, only 0.4% of the documents were of other types, such as Editorials (2), Errata (2), Notes (2), Short Surveys (1), and Retracted papers (1) (Fig. 3).

3.2. Journals on groundwater in CIS countries

The review provides an overview of journals and knowledge topics related to this academic field (Montalván-Burbano et al., 2020). The total output was distributed across 158 journals published in 111 countries, reflecting the communication patterns of scholars in this domain. Of these, 15 journals published 834 papers, accounting for 41.74% of the total, while the remaining 58.26% of papers were published in other journals. Table 1 lists the names of the 64 journals that published a minimum of 5 papers during the aforementioned period. Among these 15 journals, 'Water Resources' had the highest number of publications with 260, followed by 'Geochemistry International' with 91 papers and 'Eurasian Soil Science' with 87 papers.

3.3. Authors and their affiliated country

Our research found that 160 authors from 111 countries conducted studies on groundwater over the period from 1972 to 2023. Fig. 4 displays the 10 authors who have published more than 17 papers. Among them, Pozdniakov, S.P. leads with 32 publications, followed by Ryzhenko, B.N. with 30, Dzhamalov, R.G. with 28, Kacimov, A.R. with 26, Bereslavskii, E.N. and Zektser, I.S. each with 24, Wang, P. with 23, Pokrovsky, O.S. with 22, and Belousova, A.P. and Kharitonova, N.A. each with 17 research papers. Among this list of top authors, seven are from the Russian Federation, one from France, one from Oman, and one from China. Institutions are classified according to the quality of the articles they publish (Khasanov et al., 2021). Over a period of 51 years,

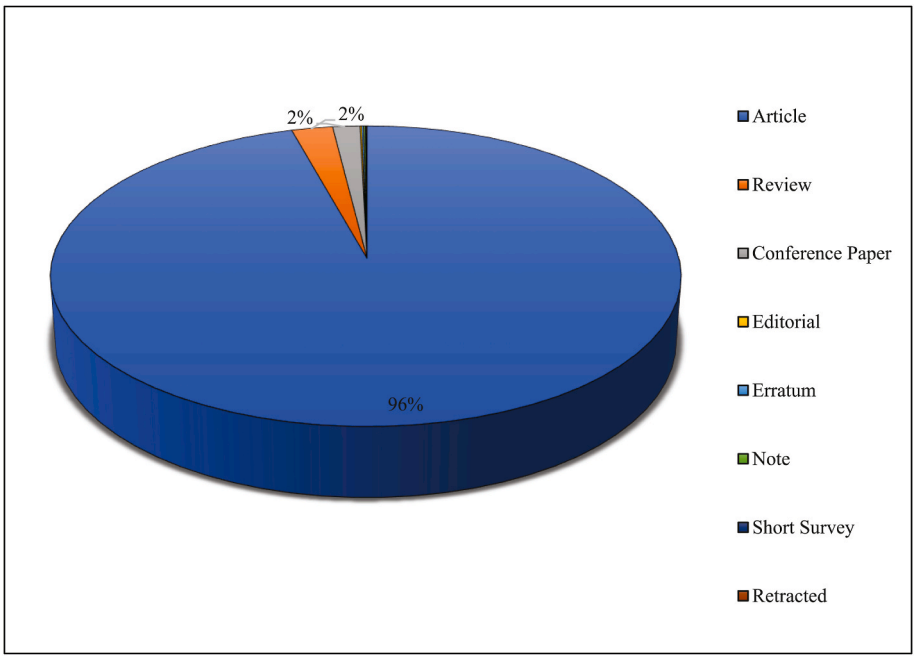

Fig. 3. Publication type on groundwater in CIS countries.

one hundred sixty different institutions collaborated to publish 1998 papers related to groundwater in CIS countries. Our analysis of the top 15 institutions' publications on groundwater allowed us to identify the most influential and productive institutions in this field. As indicated in Fig. 5, of these 15 institutions, fourteen are from the Russian Federation and only one from China. Among them, the "Russian Academy of Sciences" occupies the top position in record rank (693 records), followed by Lomonosov Moscow State University (264 records) and the Siberian Branch of the Russian Academy of Sciences (189 records)

3.4. Top countries on groundwater

The number of publications by the ten most productive countries in the field of groundwater research between 1972 and 2023 is as follows: The Russian Federation dominated with 1706 publications, followed by Kazakhstan with 158, the United States with 136, China with 104, Germany with 100, Uzbekistan with 75, the United Kingdom with 61, France with 60, Canada with 44, and Japan with 43 (Fig. 6).

3.5. Top cited papers on groundwater in CIS countries

Table 2 presents data concerning the fifteen most cited papers on groundwater in the CIS countries. These include works by Schirov et al. (1991); Zektser and Loaiciga (1993b); Howarth et al. (1996b); Chen et al. (1997); Legchenko and Shushakov (1998); Christensen et al. (2000); Persoone et al. (2003); Fine et al. (2005); Burnett et al. (2006); Thomas H. et al. (2011); Dai et al. (2012b, a); Seredin and Dai (2012); Ivshina et al. (2015); Bring et al. (2016). Together, these 15 papers have garnered a total of 6439 citations. The top 15 cited papers comprise five review articles, nine research articles, and one conference paper. Notably, fourteen of the most cited papers were published during the stable growth period, with only one paper appearing in 2016.

3.6. Top cited journals on groundwater in CIS countries

The analysis of journals' productivity and impact was conducted based on the number of articles published. Fig. 7 presents the top journals that published the highest number of papers on groundwater. To investigate the top-cited journals in this field, we first organized the source names alphabetically in the Excel file containing 1998 documents. Then, we tallied the total number of citations for each journal. Interestingly, this process yielded an updated list with potential journal names. The initial 10 journals were selected and are displayed in Fig. 7. Regarding the number of citations, the 'International Journal of Coal Geology' ranked first with 1705 citations, followed by 'Biogeochemistry' with 1448 citations, 'Science of the Total Environment' with 933 citations, and 'Geochimica et Cosmochimica Acta' with 804 citations.

3.7. Top funding sponsors and subject areas on groundwater

In the CIS countries, over the period of 1972–2023, one hundred fifty-nine different funding sponsors collaborated to publish 1187 papers on groundwater issues. Our analysis of the top 15 funding sponsors' publications on groundwater allowed us to identify the most influential and productive institutions in the field. As indicated in Fig. 8, of these 15 funding sponsors, seven were from the Russian Federation, two from Germany, two from China, one from Kazakhstan, one supported by the European Commission, and the last from the United States.

The Scopus database categorizes papers into various subject areas. Most papers on groundwater issues in CIS countries fall into seven different subject areas, as shown in Fig. 9. The Agricultural and Biological Sciences subject area encompasses 29% of the total publications, while Environmental Sciences account for 39%, Earth and Planetary Sciences for 35%, Agriculture and Biological Sciences for 17%, and the Engineering area covers 9% of the total publications.

3.8. Top co-authorships and keywords on groundwater in CIS countries

Co-authorship, keyword co-occurrences, citations, bibliographic coupling, and co-citation maps can be generated using VOSviewer based on bibliographic data. Supported file formats include.txt, .ris, and.csv from databases such as Scopus (Samir Kumar Jalal, 2019). The raw file was imported into VOSviewer, and maps of co-authorship and keyword co-occurrences were created using the software (as shown in Figs. 10 and 11). Only authors with a minimum of seven publications on the topic of groundwater were included. The analysis revealed 49 items distributed across 15 clusters: cluster 1 (7 items), cluster 2 (7 items), cluster 3 (6 items), cluster 4 (5 items), cluster 5 (5 items), cluster 6 (4

Table 1
List of the journals on groundwater by the year of publication issues in CIS countries.

Scopus Source title	Number	Scopus Source title	Number
Water Resources	260	Ecology Environment and Conservation	10
Geochemistry International	91	Advances in Water Resources	9
Eurasian Soil Science	87	Environmental Research Letters	8
Water Switzerland	50	Irrigation and Drainage	8
Doklady Earth Sciences	41	Journal of Geochemical Exploration	8
News of The National Academy of Sciences of The Republic of Kazakhstan Series of Geology and Technical Sciences	37	Journal of Water and Land Development	8
Journal of Hydrology	36	Agricultural Water Management	7
Environmental Earth Sciences	33	Quaternary International	7
Applied Geochemistry	32	Transactions Doklady of The Russian Academy of Sciences Earth Science Sections	7
Geology of Ore Deposits	30	Chemosphere	6
Russian Geology and Geophysics	30	Doklady Physics	6
Moscow University Geology Bulletin	28	Environmental Geochemistry and Health	6
Arid Ecosystems	27	Geography Environment Sustainability	6
Journal of Engineering Physics and Thermophysics	26	Geophysical Journal International	6
Radiochemistry	26	Hydrological Processes	6
Journal of Environmental Radioactivity	22	Journal of Applied Engineering Science	6
Environmental Geology	20	Journal of Volcanology and Seismology	6
Geography and Natural Resources	17	Permafrost and Periglacial Processes	6
Science of The Total Environment	17	Soil Mechanics and Foundation Engineering	6
Sustainability Switzerland	16	Water Science and Technology	6
Izvestiya Physics of The Solid Earth	15	Biology Bulletin	5
Chemical Geology	14	Earth and Planetary Science Letters	5
Contemporary Problems of Ecology	14	Environmental Science and Technology	5
Hydrogeology Journal	14	Eurasian Mining	5
Journal of Mining Science	14	Geofisica Internacional	5
Russian Journal of Pacific Geology	14	Geophysics	5
Environmental Science and Pollution Research	13	Hydrological Sciences Bulletin	5
Lithology and Mineral Resources	13	Journal of Applied Geophysics	5
Geochimica Et Cosmochimica Acta	12	Journal of Applied Mathematics and Mechanics	5
Journal of Ecological Engineering	12	Journal of Contaminant Hydrology	5
Russian Meteorology and Hydrology	12	Journal of Environmental Management and Tourism	5
Water Resources Research	12	Journal of Environmental Science and Health Part A Toxic Hazardous Substances and Environmental Engineering	5

items), cluster 7 (4 items), cluster 8 (3 items), cluster 9 (2 items), and clusters 10 to 15 (1 item each). The total link strength was 312, with 65 links.

The keyword analysis yielded 13,017 keywords. After excluding general keywords with a low relevance score and those with low occurrence (by default, a minimum of 63 occurrences of a keyword was selected to strengthen the co-occurrence results), 33 items were finally identified. Each resulting keyword is represented as a node based on the total link strength, creating a network map of all keywords. Fig. 11 shows the network map of the top 33 authors' keyword co-occurrence. The size of each node reflects the keyword's degree of importance. There are 33 items distributed over 4 clusters: cluster 1 (article, Eurasia, groundwater, ground water, irrigation, salinity, soils, surface water, water quality, water supply), cluster 2 (aquifer, groundwater flow, groundwater pollution, groundwater resources, hydrology, infiltration, numerical model), cluster 3 (chemical composition, concentration, geochemistry, hydrochemistry, hydrogeochemistry, isotopes, water chemistry), and cluster 4 (climate change, groundwater resource, permafrost, rivers, runoff, Russian Federation, Siberia). The total link strength is 7,748, with 514 links.

3.9. Role of drainage in groundwater studies

Drainage is a key aspect of groundwater management, controlling land reclamation and groundwater levels (Ayars et al., 2006). Recognizing this, groundwater resources in agricultural regions with substantial drainage can be effectively managed (van der Zee et al., 2017). Numerous articles by scientists from the CIS countries focus on the application of methods, modeling, and control of groundwater and drainage. Notable models include Arifjanov et al. (2022a), who physically and mathematically modeled the impact of rising groundwater levels on the environment and agricultural crops, particularly within the horizontal drainage effect. Emikh (2008) identified specific features of groundwater flow with drainage in agricultural land using mathematical models. Bechtold et al. (2018) evaluated the response of advanced deeply-drained systems through synthetic aperture radar, inferring water table depth dynamics under natural conditions. Hoang et al. (2017) applied multi-parameter statistical methods to complement the substantive-genetic principle of classifying drained peat soils, including descriptions of their water regimes.

Our analysis of groundwater publications for CIS countries during the period shows that approximately 40 (2%) of the publications focused on the role of drainage. The number of publications ranged from one to six papers published between 1981 and 2022 on drainage-related groundwater issues. The peak in publication number was reached in 2022 with six papers. These drainage-focused papers were published in 30 different journals of high repute. Almost 38 authors from various countries contributed to these publications. In the last five years, 15 publications related to groundwater and drainage were listed in Table 3, including works by Khayrulina and Maksimovich (2018); Limantseva et al. (2019); Okuda et al. (2020a); Dmitrieva and Buchik (2021); Shanin et al. (2021); Liu et al. (2021); Tregubov et al. (2021); Agarkov et al. (2022); Nizhegorodtcev et al. (2022); Derkachev et al. (2022); Zvereva et al. (2022); Egorova et al. (2022); Arifjanov et al. (2022b).

4. Discussion

The objectives of this study were to analyze the existing knowledge on a large scale regarding groundwater and to identify, through a systematic review, the scientific articles and research areas that have had the greatest impact on the topic. This scientometric analysis revealed that the articles published over the past 51 years have shown the most significant results in groundwater studies in the last 9 years. The annual production of articles on groundwater during the period 1972–2023 in CIS countries can be categorized into three developmental periods: the introduction period (1972–1995), the period of slight growth

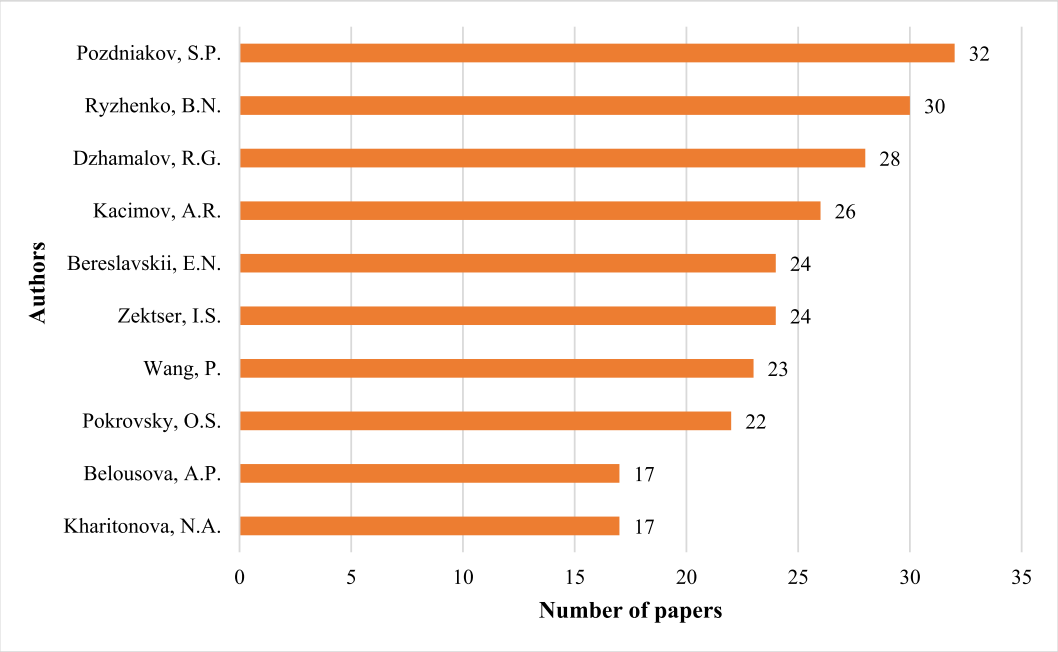

Fig. 4. List of top authors published on groundwater in CIS countries.

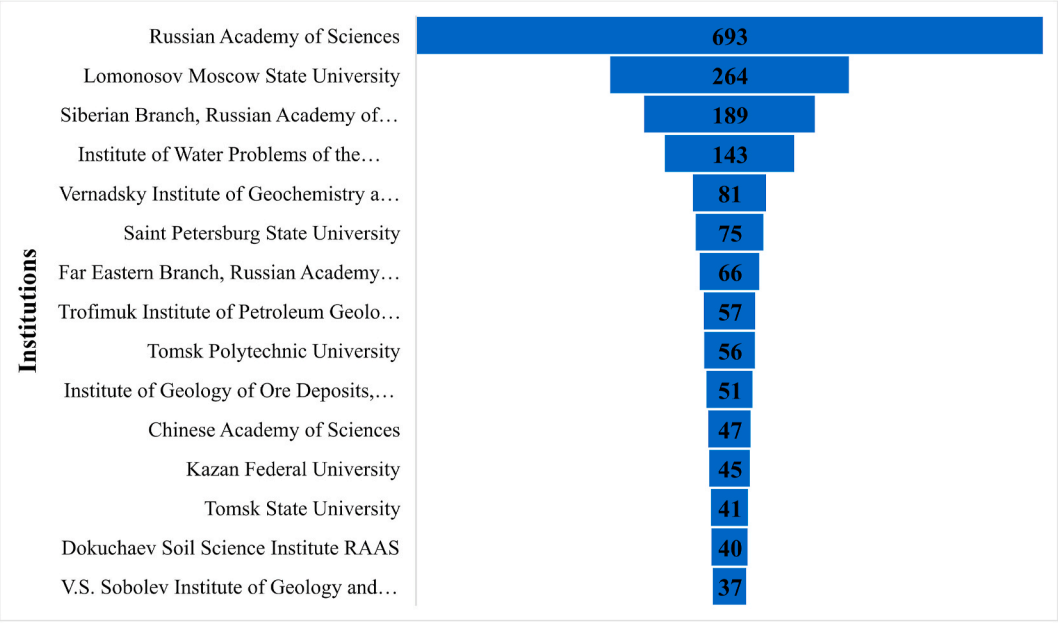

Fig. 5. List of top institutions on groundwater.

(1996–2014), and the period of stable growth (2015–2023). During the introduction period, interest in groundwater topics related to agricultural lands began with a focus on the environmental problem-solution relationship. The period of slight growth highlighted the importance of drainage in groundwater ecosystems, and this period was also marked by the collapse of the USSR, which affected the effectiveness of publishing in various countries. The stable growth period demonstrates a strengthening of research in this academic field across various topics. From the analysis of groundwater in CIS countries, the Russian Federation leads in terms of top institutions, authors, countries, and funding sponsors for groundwater research. The "Russian Academy of Sciences" holds the first position in record rank with 693 articles (34.6%). The main reason for this prominence is that the country is traditionally defined as one of the most developed in the CIS region. This may be attributed to the large number of highly regarded research centers and universities in the country.

Studies have shown the global status of sustainable water use in areas related to groundwater, finding that agriculture is the main consumer of water resources (Velasco-Muñoz et al., 2018; López-Serrano et al., 2020). In the territories of CIS countries, the connection between groundwater and the drainage of agricultural irrigated lands is of great importance. One of the primary causes of soil salinization and erosion during these periods is the rise in the underground water level (Okuda et al., 2020b). Groundwater development and topographic slope are dominant factors for spatial variation of sustainable groundwater safe yield and surface soil erosion (Hirbo Gelebo et al., 2022a). Another

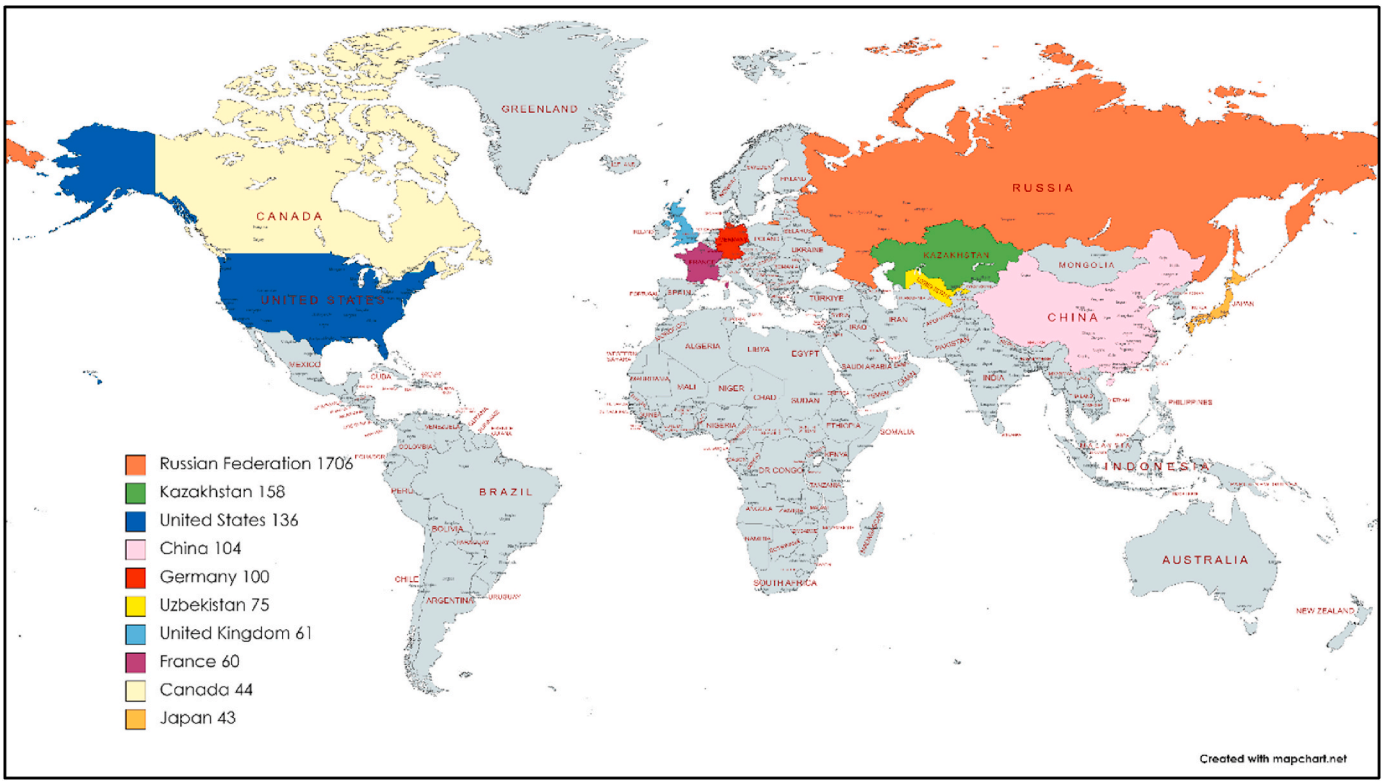

Fig. 6. List of top countries on groundwater.

Table 2
List of top cited publications on groundwater in CIS countries.

No.	Title	Journal	Corresponding author	PY	TC 2000–2022	Doc.type
1.	Regional nitrogen budgets and riverine N & P fluxes for the drainages to the North Atlantic Ocean: Natural and human influences	Biogeochemistry	Howarth R.W.	1996	1372	Article
2.	Geochemistry of trace elements in Chinese coals: A review of abundances, genetic types, impacts on human health, and industrial utilization	International Journal of Coal Geology	Dai S.	2012	850	Review
3.	Quantifying submarine groundwater discharge in the coastal zone via multiple methods	Science of the Total Environment	Burnett W.C	2006	688	Review
4.	Coal deposits as potential alternative sources for lanthanides and yttrium	International Journal of Coal Geology	Seredin V.V.	2012	578	Review
5.	Detection of crystalline hematite mineralization on Mars by the Thermal Emission Spectrometer: Evidence for near-surface water	Journal of Geophysical Research: Planets	Christensen P.R.	2000	408	Article
6.	A practical and user-friendly toxicity classification system with microbiotests for natural waters and wastewaters	Environmental Toxicology	Persoone G.	2003	349	Article
7.	Operational earthquake forecasting: State of knowledge and guidelines for utilization	Annals of Geophysics	Jordan T.H.	2011	318	Article
8.	Cabauw experimental results from the Project for Intercomparison of Land-Surface Parameterization Schemes	Journal of Climate	Chen T.H.	1997	298	Article
9.	The Grand Banks landslide-generated tsunami of November 18, 1929: Preliminary analysis and numerical modeling	Marine Geology	Fine I.V.	2005	275	Conference paper
10.	Oil spill problems and sustainable response strategies through new technologies	Environmental Science: Processes and Impacts	Ivshina I.B.	2015	248	Review
11.	Mineralogical and geochemical compositions of the coal in the Guanbanwusu Mine, Inner Mongolia, China: Further evidence for the existence of an Al (Ga and REE) ore deposit in the Jungar Coalfield	International Journal of Coal Geology	Dai S.	2012	243	Article
12.	Arctic terrestrial hydrology: A synthesis of processes, regional effects, and research challenges	Journal of Geophysical Research: Biogeosciences	Bring A.	2016	228	Review
13.	A new direct non-invasive groundwater detection technology for Australia	Exploration Geophysics	Schirov M.	1991	204	Article
14.	Groundwater fluxes in the global hydrologic cycle: past, present and future	Journal of Hydrology	Zektser I.S.	1993	197	Article
15.	Inversion of surface NMR data	Geophysics	Legchenko A.V.	1998	183	Article

*PY – Published year, * TC – Total citation.

important factor affecting hillslope soil erosion is hydrological characteristics closely related to groundwater seepage (GWS), which is the exfiltration of shallow groundwater at the soil surface (Hirbo Gelebo et al., 2022b). The main cause of these issues is often the failure or absence of an adequate drainage system. The damage caused by soil salinization and soil erosion to the national economy of CIS countries is

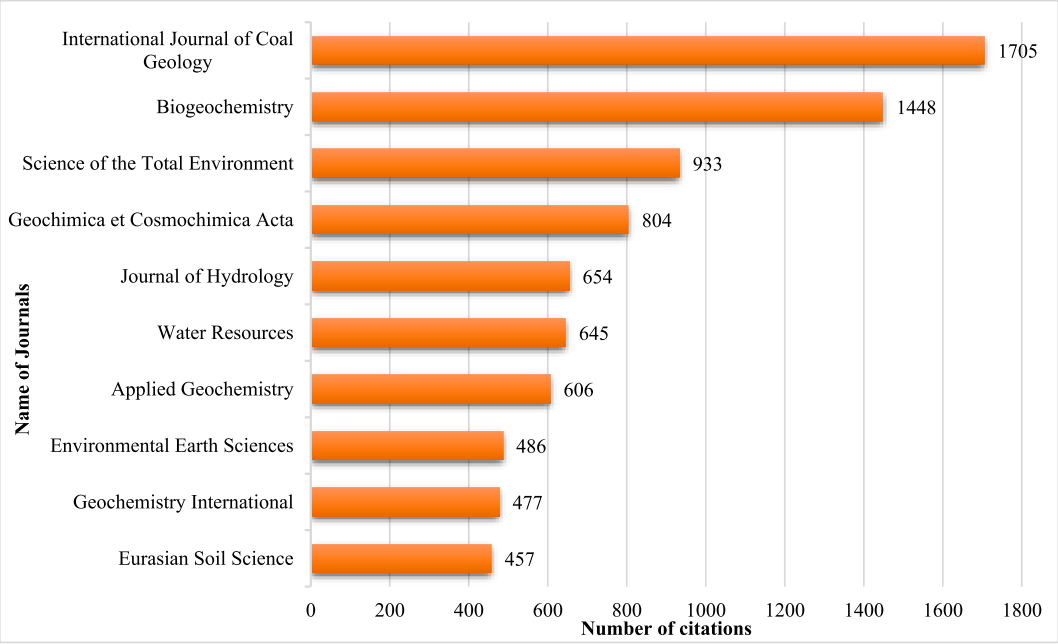

Fig. 7. Top cited journals on groundwater in CIS countries.

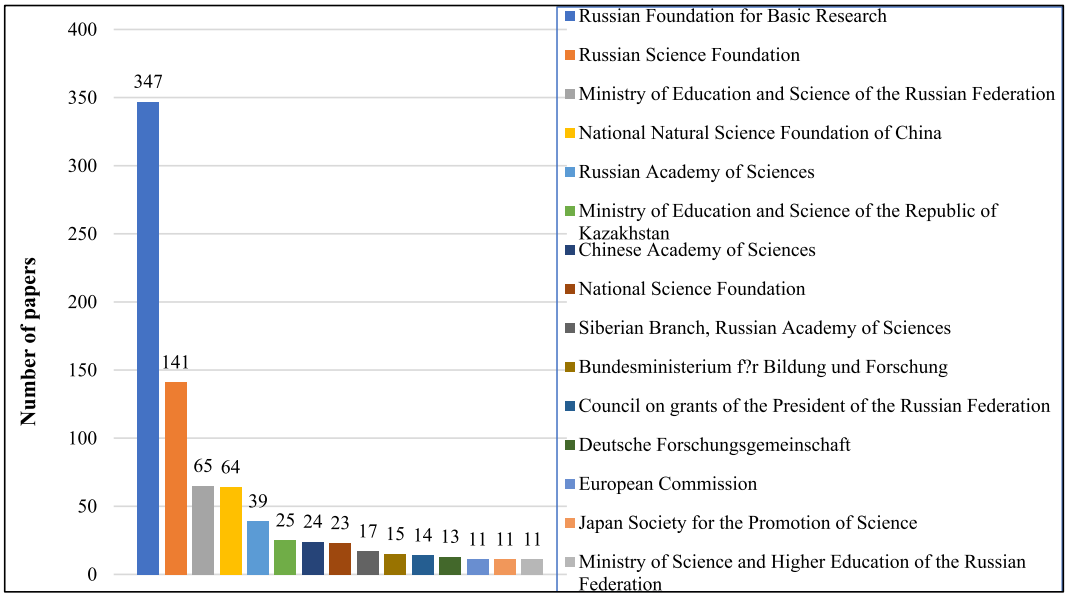

Fig. 8. List of top funding sponsors on groundwater in CIS countries.

extremely large, impacting not only agricultural land but also ancient historical monuments, remnants of fortresses, buildings, structures, asphalt foundations, livestock pastures, and underground communications (Gafurova and Juliev 2021; Makhkamova et al., 2022).

This study analyzes the scientific production related to groundwater, particularly emphasizing the importance of drainage in agricultural lands, using bibliometric methods. Various studies have employed bibliometric models in groundwater ecosystems to understand key concepts and theories associated with water supply sources. For instance, Vander Wilde and Newell (2021), developed a robust bibliometric review, integrating deep and broad content on ecosystem services.

The bibliometric analysis demonstrates the intellectual interaction, thematic strengths, and evolving interest of various focus groups integrating scientific methods to address problems related to groundwater and its ecosystems. Additionally, as shown by Gricelda Herrera-Franco et al. (2022), this study enables the establishment of new trends in agricultural development issues concerning irrigation efficiency, wastewater reuse, mining and treatment, and climate change within a circular economy framework tied to sustainability and life cycle assessment.

Another significant aspect is the future challenges of groundwater. According to Jörg Lewandowski et al. (2020), hese include surface water interactions, recent advances, interdisciplinary challenges, and depth variations in groundwater (Kishor et al., 2022). Furthermore, the identification of aquifers suitable for groundwater development is crucial (Bhatnagar et al., 2022).

Based on the quantitative analysis, the most common contexts are “groundwater,” with 1032 documents representing 7.92% of the total, followed by “aquifers” (271 documents), “hydrogeology” (172 documents), and “groundwater resources” (142 documents). These analyses

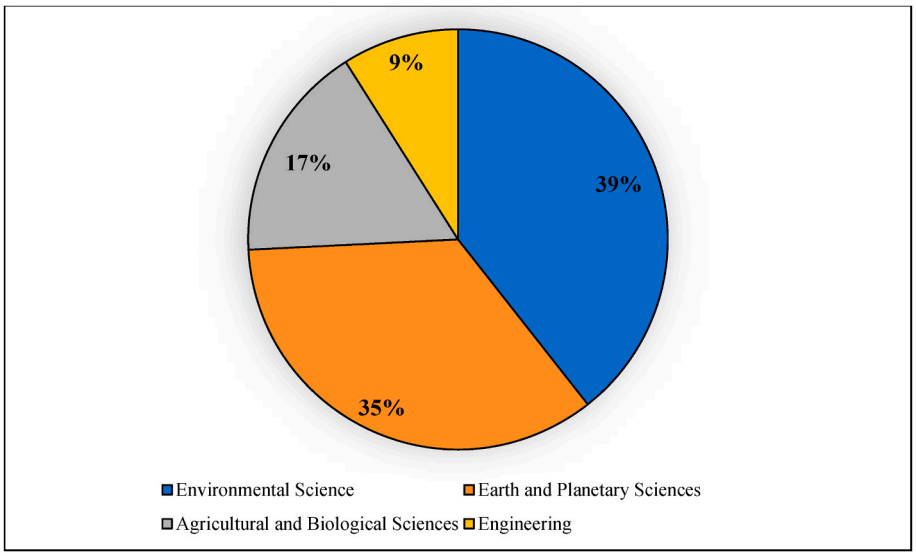

Fig. 9. List of subject areas on groundwater in CIS countries.

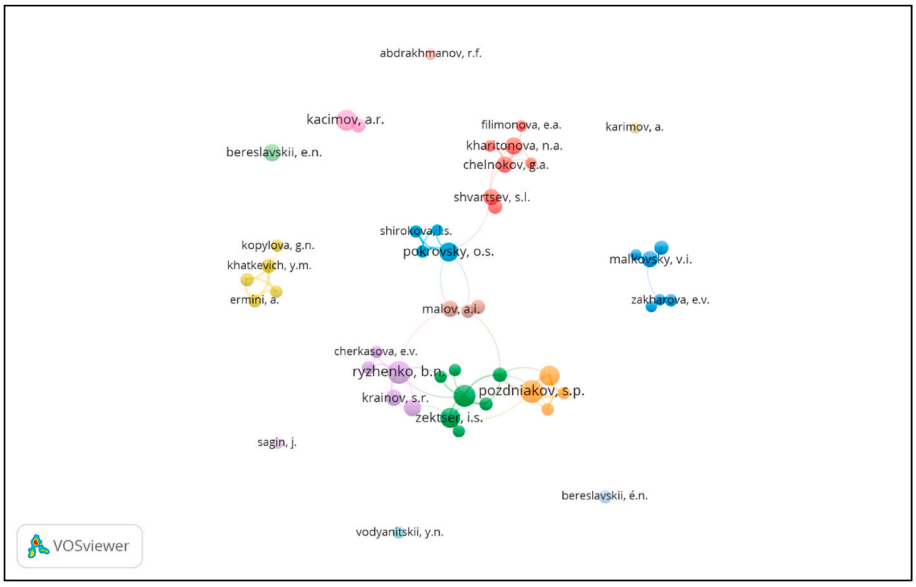

Fig. 10. Network map of top co-authorships based on the total link strength.

highlight the issues related to the rise in groundwater levels in CIS countries, often due to a lack of technical control in drainage systems (Ayars et al., 2006; Balla et al., 2014; Drovovozova et al., 2021). Neglecting technical monitoring of drainage systems in irrigated lands is a primary cause of soil salinity, leading to increased salinization of irrigated lands and groundwater levels.

In summary, this work focuses on maintaining groundwater, particularly considering the importance of drainage in agricultural lands. Our analysis of groundwater publications for CIS countries over 51 years revealed that only 40 publications were specifically about drainage-related groundwater issues, with publications spanning from 1981 to 2022. These articles discuss salinization of groundwater, water pollution, land reclamation, deterioration of drinking water, and drainage connections in cities and forests. Topics include groundwater and ecosystem problems, agricultural development issues around irrigation efficiency, wastewater reuse, mining, treatment, climate change in a circular economy scheme, sustainability, and life cycle assessment. It is evident that groundwater is interconnected with many areas, among which the issue of drainage is crucial. However, our analysis indicates that over 51 years, only 40 publications specifically focused on drainage-related groundwater issues.

4.1. Groundwater management during and after the Soviet Union era

Groundwater management is considered fundamentally important, as it helps tailor groundwater management to each study area. This management should align as closely as possible with the area's natural conditions to be effectively and successfully used for prediction and management purposes (Norouzi Khatiri et al., 2023). During the USSR period, groundwater management was accomplished through sixteen years of investigative programs and research. While progress was notable, there was a need for more methods for the regional analysis of groundwater systems. A deeper understanding of geochemistry and the quality of groundwater was essential (Johnson 1972). From 1980 to 1990, in many industrial sites covered by weakly pervious soils, there were instances of rising groundwater levels and the formation of new

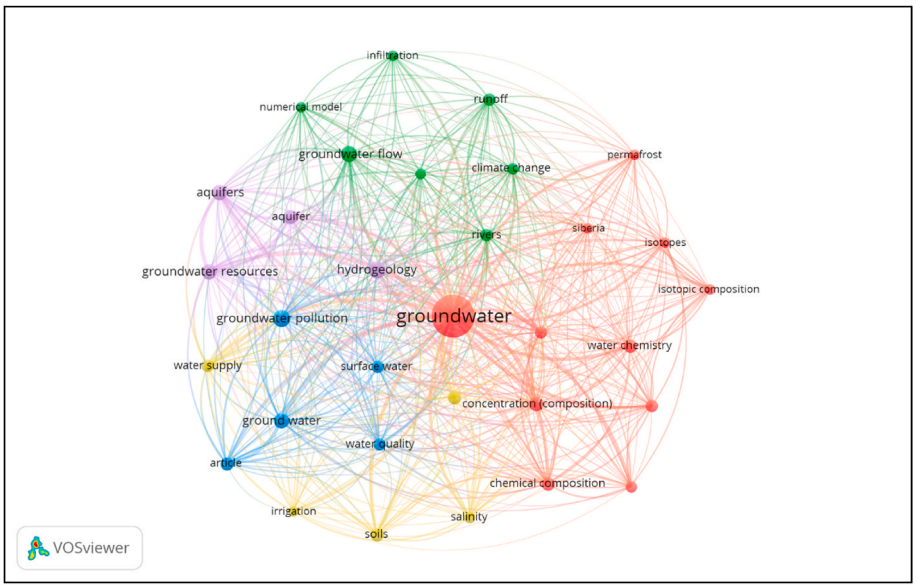

Fig. 11. Network map of top keywords based on the total link strength.

leaky aquifers. This led to the partial inundation of deep building components and structures. Therefore, groundwater began to acquire significant importance, especially regarding its long-term impact (Anpilov 1990). Up until 1991, groundwater management was coordinated by the central government of the Soviet Union in conjunction with its riparian member republics using a benefit-sharing concept. Even after the fall of the Soviet Union, there was a general consensus that this benefit-sharing agreement supported optimized basin water use. It was formally extended under the independent states through the 1992 Cooperation in Joint Management, Use, and Protection of Interstate Sources of Water Resources Agreement, signed by the Water Resources Ministers of five central Asian states (Kyrgyzstan, Uzbekistan, Kazakhstan, Turkmenistan, and Tajikistan) (ICWC, 1992). However, the implementation of this agreement has been less than perfect.

Integrated Water Resources Management (IWRM) emerged as the core mantra of water management discourse following the codification of its ideas in the Dublin Declaration of 1992. Defined by the Global Water Partnership (GWP, 2000) as 'a process that promotes coordinated development and management of water, land, and related resources to maximize the resultant economic and social welfare equitably without compromising the sustainability of vital ecosystems,' IWRM's basic premise is the use of the river basin as the fundamental management unit. The theoretical appeal of the IWRM concept is clear, yet implementing its principles is complex, especially in developing countries where resources for such management are often limited. This complexity partly stems from the fact that basin boundaries almost never coincide with the political boundaries in which water use decisions are made. Finally, with rapid population growth and socio-economic development in CIS countries, there is a pressing need to better link groundwater research with water planning and management, incorporating social, economic, and legal aspects.

5. Conclusion

This work focused on groundwater research hotspots and potential research directions in the CIS countries from 1972 to 2023, using bibliometric approaches based on the online Scopus database. In this bibliometric analysis, we collected, reviewed, and analyzed 1998 publications. The continued and stable growth in the number of articles between 2015 and 2023 implies that groundwater is increasingly attracting attention. This period represents a key phase of exponential growth, accounting for 54.75% of the total documents. The peak in the number of publications was reached with 188 articles in 2022, followed by 173 in 2021, indicating consistent growth in this field. The Russian Federation contributed the most publications, followed by Kazakhstan, the United States, China, Germany, Uzbekistan, the United Kingdom, France, Canada, and Japan. Through this analysis, we observed that land salinization in the CIS countries has become a serious issue, influenced by many factors, including the rise in groundwater levels. A major contributing factor is the poor performance of drainage systems in these countries, often leading to their complete dysfunction. Neglecting technical monitoring of these systems in irrigated lands is a primary cause of rising groundwater levels, which could lead to increased salinization of irrigated lands in the future. Such neglect may result in land degradation, impacting not only agriculture but also human health, animal loss, and causing political and economic difficulties in the CIS countries. Key reasons for these challenges include inadequate data exchange systems and a lack of international cooperation, resulting in limited joint projects.

Furthermore, water resources, particularly in CIS countries, are limited and predominantly affected by agricultural irrigation, leading to moderate pollution. In recent years, with rapid population growth and socio-economic development in the CIS countries, there is a pressing need to better integrate groundwater research with water planning and management, encompassing social, economic, and legal aspects. Groundwater management has been a challenging issue since the time of the USSR and continues to be so. Systematic approaches, computational tools, new optimization and simulation models, and their application in groundwater planning and management have developed rapidly in recent decades. Groundwater systems can be effectively analyzed by identifying their components and studying their interrelationships.

The primary audience for this paper includes agricultural producers, policymakers impacting agriculture drainage and groundwater policies, academic and government agency researchers, and the general public. Proper management of these issues can foster more international collaborative projects and new publications, not only in groundwater but also in other areas. Addressing these challenges is imperative for the future. Additionally, international research on groundwater would benefit from increased scientific exchange on this topic, particularly among emerging and developed countries, and between agricultural and groundwater science communities, as well as stakeholders and scientists.

Table 3
List of publications about drainage based on groundwater in CIS countries.

N⁰	Title	Journal	Corresponding author	PY	Doc. type
1	Model of urban groundwater level management in drainage systems	Acta Hydrologica Slovaca	Arifjanov A.	2022	Article
2	Formation of mine drainage in the Far Eastern region and its impact on the ecosphere and public health	Mining Science and Technology (Russian Federation)	Zvereva V.P.	2022	Article
3	Nature of radioactivity of quarry drainage waters in the Novosibirsk region	Mining Science and Technology (Russian Federation)	Derkachev A.S.	2022	Article
4	Layer drainage of fibrous materials in the composition of the ground dams	Magazine of Civil Engineering	Nizhegorodtcev E.	2022	Article
5	Optimization of the drainage system of overburden dumps using geofiltration modeling	Caspian Journal of Environmental Sciences	Agarkov N.B.	2022	Article
6.	Neptunium behavior in conditions of deep stratum-collector of liquid radioactive waste	Applied Geochemistry	Egorova T.B.	2022	Article
7	Geochemical distribution and speciation of thallium in groundwater impacted by acid mine drainage (Southern China)	Chemosphere	Liu Y.	2021	Article
8	Simulation modelling of greenhouse gas balance in continuous-cover forestry of Norway spruce stands on nutrient-rich drained peatlands	Forest Ecology and Management	Shanin V.	2021	Article
9	Hydrological conditions of drained lake basins of the anadyr lowland under changing climatic conditions	Geography, Environment, Sustainability	Tregubov O.D.	2021	Article
10	Thermal Regime of River Water as a Response to Climatic Processes in the Upper Don Drainage Basin	Arid Ecosystems	Dmitrieva V.A.	2021	Article
11	Water and salt balance in agricultural lands under leaching with shallow subsurface drainage used in combination with cut-drains	Water (Switzerland)	Okuda Y.	2020	Article
12	Current Geo-Ecological Problems Within the Lake Khanka Drainage Basin	Geography and Natural Resources	Baklanov P.Y.	2019	Article
13	Acidic Drainage at the Pavlovskoe Ore Deposit, Novaya Zemlya Archipelago	Geochemistry International	Limantseva O.A.	2019	Article
14	Groundwater hydro chemical regime and soil salinity under long-term operation on tasotkel irrigated and drained lands of Zhambyl Region	News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences	Kulagin V.V.	2019	Article
15	Influence of Drainage with High Levels of Water-Soluble Salts on the Environment in the Verhnekamskoe Potash Deposit, Russia	Mine Water and the Environment	Khayrulina E.	2018	Article

aPY – Published year.

CRediT authorship contribution statement

Zulfiya Kannazarova: Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Writing – original draft. **Mukhiddin Juliev:** Conceptualization, Investigation, Project administration, Resources, Supervision, Validation, Writing – review & editing. **Ashirbek Muratov:** Formal analysis, Supervision, Writing – review & editing. **Jilili Abuduwaili:** Conceptualization, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors have no conflict of interest.

Data availability

Data will be made available on request.

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References

Abduraimova, D., Ibragimova, Z., Otakhonov, M., Khusanova, D., 2021. Deformation processes in open drainages. E3S Web Conf 264, 03010. https://doi.org/10.1051/e3sconf/202126403010.

Agarkov, N.B., Khaustov, V.V., Malikov, A.M., et al., 2022. Optimization of the drainage system of overburden dumps using geofiltration modeling. CJES 20. https://doi.org/10.22124/cjes.2022.5413.

Alikhanov, B., Juliev, M., Alikhanova, S., Mondal, I., 2021. Assessment of influencing factor method for delineation of groundwater potential zones with geospatial techniques. Case study of Bostanlik district, Uzbekistan. Groundwater for Sustainable Development 12, 100548. https://doi.org/10.1016/j.gsd.2021.100548.

Anpilov, V.E., 1990. Mechanism of formation of long-term groundwater regime in industrial site bases. Soil Mech. Found. Eng. 27, 59–61. https://doi.org/10.1007/BF02306102.

Arifjanov, A., Otaxonov, M., Samiev, L., Akmalov, S., 2019. Hydraulic calculation of horizontal open drainages. E3S Web Conf 97, 05039. https://doi.org/10.1051/e3sconf/20199705039.

Arifjanov, A., Samiev, L.N., Abdulkhaev, Z., et al., 2022a. Model of urban groundwater level management in drainage systems. AHS 23, 172–179. https://doi.org/10.31577/ahs-2022-0023.02.0019.

Arifjanov, A., Samiev, L.N., Abdulkhaev, Z., et al., 2022b. Model of urban groundwater level management in drainage systems. AHS 23, 172–179. https://doi.org/10.31577/ahs-2022-0023.02.0019.

Ayars, J.E., Christen, E.W., Hornbuckle, J.W., 2006. Controlled drainage for improved water management in arid regions irrigated agriculture. Agric. Water Manag. 86, 128–139. https://doi.org/10.1016/j.agwat.2006.07.004.

Bagard, M.-L., Chabaux, F., Pokrovsky, O.S., et al., 2011. Seasonal variability of element fluxes in two Central Siberian rivers draining high latitude permafrost dominated areas. Geochem. Cosmochim. Acta 75, 3335–3357. https://doi.org/10.1016/j.gca.2011.03.024.

Balla, D., Omar, M., Maassen, S., et al., 2014. Efficiency of duckweed (lemnaceae) for the desalination and treatment of agricultural drainage water in detention reservoirs. In: Mueller, L., Saparov, A., Lischeid, G. (Eds.), Novel Measurement and Assessment Tools for Monitoring and Management of Land and Water Resources in Agricultural Landscapes of Central Asia. Springer International Publishing, Cham, pp. 423–440.

Barandun, M., Fiddes, J., Scherler, M., et al., 2020. The state and future of the cryosphere in Central Asia. Water Security 11, 100072. https://doi.org/10.1016/j.wasec.2020.100072.

Bechtold, M., Schlaffer, S., Tiemeyer, B., De Lannoy, G., 2018. Inferring water table depth dynamics from ENVISAT-ASAR C-band backscatter over a range of peatlands from deeply-drained to natural conditions. Rem. Sens. 10, 536. https://doi.org/10.3390/rs10040536.

Bhatnagar, S., Taloor, A.K., Roy, S., Bhattacharya, P., 2022. Delineation of aquifers favorable for groundwater development using Schlumberger configuration resistivity survey techniques in Rajouri district of Jammu and Kashmir, India. Groundwater for Sustainable Development 17, 100764. https://doi.org/10.1016/j.gsd.2022.100764.

Bobrov, P.A., Slyunchev, O.M., Semenova, T.A., 2015. Radionuclide removal from radioactively contaminated drainage water and groundwater by precipitation and sorption methods. Radiochemistry 57, 537–541. https://doi.org/10.1134/S106636221505015X.

Bose, S., Mazumdar, A., Basu, S., 2023. Evolution of groundwater quality assessment on urban area- a bibliometric analysis. Groundwater for Sustainable Development 20, 100894. https://doi.org/10.1016/j.gsd.2022.100894.

Bring, A., Fedorova, I., Dibike, Y., et al., 2016. Arctic terrestrial hydrology: a synthesis of processes, regional effects, and research challenges. J Geophys Res Biogeosci 121, 621–649. https://doi.org/10.1002/2015JG003131.

Burnett, W.C., Aggarwal, P.K., Aureli, A., et al., 2006. Quantifying submarine groundwater discharge in the coastal zone via multiple methods. Sci. Total Environ. 367, 498–543. https://doi.org/10.1016/j.scitotenv.2006.05.009.

Cancino, C., Merigó, J.M., Coronado, F., et al., 2017. Forty years of computers & industrial engineering: a bibliometric analysis. Comput. Ind. Eng. 113, 614–629. https://doi.org/10.1016/j.cie.2017.08.033.

Charzyński, P., Urbańska, M., Franco Capra, G., et al., 2022. A global perspective on soil science education at third educational level; knowledge, practice, skills and challenges. Geoderma 425, 116053. https://doi.org/10.1016/j.geoderma.2022.116053.

Che Nordin, N.F., Mohd, N.S., Koting, S., et al., 2021. Groundwater quality forecasting modelling using artificial intelligence: a review. Groundwater for Sustainable Development 14, 100643. https://doi.org/10.1016/j.gsd.2021.100643.

Chen, T.H., Henderson-Sellers, A., Milly, P.C.D., et al., 1997. Cabauw experimental results from the project for intercomparison of land-surface parameterization schemes. J. Clim. 10, 1194–1215. https://doi.org/10.1175/1520-0442(1997)010<1194:CERFTP>2.0.CO;2.

Christensen, P.R., Bandfield, J.L., Clark, R.N., et al., 2000. Detection of crystalline hematite mineralization on mars by the thermal emission spectrometer: evidence for near-surface water. J. Geophys. Res. 105, 9623–9642. https://doi.org/10.1029/1999JE001093.

Dai, S., Jiang, Y., Ward, C.R., et al., 2012a. Mineralogical and geochemical compositions of the coal in the Guanbanwusu Mine, Inner Mongolia, China: further evidence for the existence of an Al (Ga and REE) ore deposit in the Jungar Coalfield. Int. J. Coal Geol. 98, 10–40. https://doi.org/10.1016/j.coal.2012.03.003.

Dai, S., Ren, D., Chou, C.-L., et al., 2012b. Geochemistry of trace elements in Chinese coals: a review of abundances, genetic types, impacts on human health, and industrial utilization. Int. J. Coal Geol. 94, 3–21. https://doi.org/10.1016/j.coal.2011.02.003.

de Sousa, F.D.B., 2021. Management of plastic waste: a bibliometric mapping and analysis. Waste Manag. Res. 39, 664–678. https://doi.org/10.1177/0734242X21992422.

delRío-Rama, M., Maldonado-Erazo, C., Álvarez-García, J., Durán-Sánchez, A., 2020. Cultural and natural resources in tourism island: bibliometric mapping. Sustainability 12, 724. https://doi.org/10.3390/su12020724.

Derkachev, A.S., Maksimova, A.A., Novikov, D.A., et al., 2022. Nature of radioactivity of quarry drainage waters in the Novosibirsk region. Min. Sci. Technol. 7, 216–230. https://doi.org/10.17073/2500-0632-2022-3-216-230.

Dmitrieva, V.A., Buchik, S.V., 2021. Thermal regime of river water as a response to climatic processes in the upper don drainage basin. Arid Ecosyst 11, 109–115. https://doi.org/10.1134/S2079096121010066.

Drovovozova, T.I., Mariach, S.A., Panenko, N.N., 2021. Technical solutions for cleaning drainage water from irrigated areas. IOP Conf. Ser. Earth Environ. Sci. 677, 042094 https://doi.org/10.1088/1755-1315/677/4/042094.

Dukhovny, V., Kenjabaev, S., Yakubov, S., Umirzakov, G., 2018a. Controlled subsurface drainage as a strategy for improved water management in irrigated agriculture of Uzbekistan: controlled subsurface drainage in agriculture of Uzbekistan. Irrigat. Drain. 67, 112–123. https://doi.org/10.1002/ird.2259.

Dukhovny, V., Kenjabaev, S., Yakubov, S., Umirzakov, G., 2018b. Controlled subsurface drainage as a strategy for improved water management in irrigated agriculture of Uzbekistan: controlled subsurface drainage in agriculture of Uzbekistan. Irrigat. Drain. 67, 112–123. https://doi.org/10.1002/ird.2259.

Durán-Sánchez, A., Álvarez-García, J., González-Vázquez, E., Del Río-Rama, M. de la C., 2020. Wastewater management: bibliometric analysis of scientific literature. Water 12, 2963. https://doi.org/10.3390/w12112963.

Efremova, T.T., Ovchinnikova, T.M., Sukhovol'skii, V.G., 2006. Multiparametric analysis of soil properties in the drained forest bogs of Western Siberia. Eurasian Soil Sci. 39, 588–596. https://doi.org/10.1134/S1064229306060020.

Egamberdieva, D., Renella, G., Wirth, S., Islam, R., 2010. Secondary salinity effects on soil microbial biomass. Biol. Fertil. Soils 46, 445–449. https://doi.org/10.1007/s00374-010-0452-1.

Egorova, T.B., Ayu, Romanchuk, Yapaskurt, V.O., et al., 2022. Neptunium behavior in conditions of deep stratum-collector of liquid radioactive waste. Appl. Geochem. 147, 105487 https://doi.org/10.1016/j.apgeochem.2022.105487.

Emikh, V.N., 2008. Mathematical models of groundwater flow with a horizontal drain. Water Resour. 35, 205–211. https://doi.org/10.1134/S0097807808020097.

Fine, I.V., Rabinovich, A.B., Bornhold, B.D., et al., 2005. The Grand Banks landslide-generated tsunami of November 18, 1929: preliminary analysis and numerical modeling. Mar. Geol. 215, 45–57. https://doi.org/10.1016/j.margeo.2004.11.007.

Gafurova, L., Juliev, M., 2021. Soil degradation problems and foreseen solutions in Uzbekistan. In: Dent, D., Boincean, B. (Eds.), Regenerative Agriculture. Springer International Publishing, Cham, pp. 59–67.

Galkin, A.N., Krasovskaya, I., Pavlovskiy, A., Shernyov, O., 2022. Regional analysis of the occurrence and spread of engineering-geological processes in the republic of Belarus. IZVESTIYA 333, 202–214. https://doi.org/10.18799/24131830/2022/4/3479.

Global Water Partnership (GWP), 2000. Global water partnership (GWP) (2000). Integrated water resources management. GWP technical advisory committee. TAC background papers No.4. GWP, Stockholm, Sweden 67.

Gulmammadov, C., Mammadova, Makhluga, Tagiyev, Allahverdi, 2022. HYDROGEOLOGICAL CONDITIONS OF THE SHIRVAN STEPPE OF AZERBAIJAN. https://doi.org/10.24412/1932-2321-2022-470-274-281.

Gyanendra, Y., Yumnam, G., Alam, W., Singh, ChI., 2022. A bibliometric analysis and assessment of scientific studies trend on groundwater research in India during 1989–2020. Arabian J. Geosci. 15, 1417. https://doi.org/10.1007/s12517-022-10707-0.

Herrera-Franco, G., Carrión-Mero, P., Montalván-Burbano, N., et al., 2022. Bibliometric analysis of groundwater's life cycle assessment research. Water 14, 1082. https://doi.org/10.3390/w14071082.

Hill, A., Minbaeva, C., Wilson, A., Satylkanov, R., 2017. Hydrologic controls and water vulnerabilities in the naryn river basin, Kyrgyzstan: a socio-hydro case study of water stressors in central asia. Water 9, 325. https://doi.org/10.3390/w9050325.

Hirbo Gelebo, A., Kasiviswanthan, K.S., Khare, D., 2022a. A spatial-temporal assessment of groundwater development in response to soil erosion. Groundwater for Sustainable Development 18, 100801. https://doi.org/10.1016/j.gsd.2022.100801.

Hirbo Gelebo, A., Kasiviswanthan, K.S., Khare, D., 2022b. A spatial-temporal assessment of groundwater development in response to soil erosion. Groundwater for Sustainable Development 18, 100801. https://doi.org/10.1016/j.gsd.2022.100801.

Hoang, Q.T., Tran, T.N.T., Le, N.N.H., 2017. Reinforced embankment by using intergrated methods of groundwater drainage, filling pile and soil mixing pile. Sci. Technol. Dev. J 20, 68–75. https://doi.org/10.32508/stdj.v20iK4.1120.

Howarth, R.W., Billen, G., Swaney, D., et al., 1996a. Regional nitrogen budgets and riverine N & P fluxes for the drainages to the North Atlantic Ocean: natural and human influences. Biogeochemistry 35, 75–139. https://doi.org/10.1007/BF02179825.

Howarth, R.W., Billen, G., Swaney, D., et al., 1996b. Regional nitrogen budgets and riverine N & P fluxes for the drainages to the North Atlantic Ocean: natural and human influences. Biogeochemistry 35, 75–139. https://doi.org/10.1007/BF02179825.

ICWC, 1992. Interstate Coordination Water Commission (ICWC) (1992). Agreement between the Republic of Kazakhstan, the Republic of Uzbekistan, the Republic of Tajikistan and Turkmenistan on Cooperation in the Field of Joint Water Resources Management and Conservation O Interstate Sources. Intergovernmental Agreements

of Central Asia States. CAWATERinfo. http://www.cawater-info.net/library/ca_e.htm. (Accessed 10 December 2009).
Ivanovich-Pykhtin, A., Vladimirovich-Tomakov, M., Alexandrovna-Tomakova, I., et al., 2019. Problems of rational use and protection of groundwater within the Russian Federation. J Appl Eng Science 17, 425–430. https://doi.org/10.5937/jaes17-22883.
Ivshina, I.B., Kuyukina, M.S., Krivoruchko, A.V., et al., 2015. Oil spill problems and sustainable response strategies through new technologies. Environ. Sci.: Process. Impacts 17, 1201–1219. https://doi.org/10.1039/C5EM00070J.
Ivushkin, K., Bartholomeus, H., Bregt, A.K., et al., 2019. Global mapping of soil salinity change. Rem. Sens. Environ. 231, 111260 https://doi.org/10.1016/j.rse.2019.111260.
Jalankuzov, T., Suleimenov, B., Busscher, W.J., et al., 2013. Irrigated cotton grown on sierozem soils in south Kazakhstan. Commun. Soil Sci. Plant Anal. 44, 3391–3399. https://doi.org/10.1080/00103624.2013.847449.
Johnson, 1972. Report on groundwater. Hydrol. Sci. Bull. 17, 44–51. https://doi.org/10.1080/02626667209493801.
Juliev, M., Matyakubov, B., Khakberdiev, O., et al., 2022. Influence of erosion on the mechanical composition and physical properties of serozems on rainfed soils, Tashkent province, Uzbekistan. IOP Conf. Ser. Earth Environ. Sci. 1068, 012005 https://doi.org/10.1088/1755-1315/1068/1/012005.
Jumaniyazov, I., Juliev, M., Orazbaev, A., Reimov, T., 2023. Marginal lands: a review of papers from the Scopus database published in English for the period of 1979–2022. Soil Sci Ann 74, 1–13. https://doi.org/10.37501/soilsa/169657.
Kannazarova, Z., Muratov, A.R., 2022. Assessment of the technical condition of reclaim systems and trends in the development of their operation technologies. JAPCA 4, 59.
Kannazarova, Z., Balabanov, V.I., Lee, A., 2021. Advanced method for cleaning horizontal closed drainage. Prirodoobustrojstvo 36–40. https://doi.org/10.26897/1997-6011-2021-3-36-40.
Khasanov, S., Juliev, M., Uzbekov, U., et al., 2021. Landslides in Central Asia: a review of papers published in 2000–2020 with a particular focus on the importance of GIS and remote sensing techniques. GeoScape 15, 134–145. https://doi.org/10.2478/geosc-2021-0011.
Khayrulina, E., Maksimovich, N., 2018. Influence of drainage with high levels of water-soluble salts on the environment in the verhnekamskoe potash deposit, Russia. Mine Water Environ. 37, 595–603. https://doi.org/10.1007/s10230-017-0509-6.
Kireeva, T.K., Salikhov, F.S., Ayu, Bychkov, Kharitonova, N.A., 2020. Chemical composition and parameters of formation of the waters of some thermal springs in Tajikistan. Geochem. Int. 58, 423–434. https://doi.org/10.1134/S0016702920030064.
Kishor, K., Patel, M., Bhattacharya, P., et al., 2022. Sources, spatio-temporal distribution and depth variations in groundwater salinity of the semi-arid Rohtak district, Haryana, India. Groundwater for Sustainable Development 18, 100790. https://doi.org/10.1016/j.gsd.2022.100790.
Knorr, H., Theesfeld, I., Soliev, S., 2022. License to drill: typology of groundwater use regulations in agriculture of Uzbekistan. Int. J. Water Resour. Dev. 38, 815–835. https://doi.org/10.1080/07900627.2021.1924633.
Kopecký, M., Ondrášik, M., Antolová, D., 2013. Horizontal drains as effective measure for landslide remediation. Studia Geotechnica Mech. 35, 129–141. https://doi.org/10.2478/sgem-2013-0011.
Kumar Jalal, Samir, 2019. Co-authorship and co-occurrences analysis using BibliometrixR package: a case study of India and Bangladesh. Ann. Libr. Inf. Stud. 2, 57–64.
Legchenko, A.V., Shushakov, O.A., 1998. Inversion of surface NMR data. Geophysics 63, 75–84. https://doi.org/10.1190/1.1444329.
Lewandowski, J., Meinikmann, K., Krause, S., 2020. Groundwater–surface water interactions: recent advances and interdisciplinary challenges. Water 12, 296. https://doi.org/10.3390/w12010296.
Limantseva, O.A., Ryzhenko, B.N., Cherkasova, E.V., 2019. Acidic drainage at the pavlovskoe ore deposit, novaya zemlya archipelago. Geochem. Int. 57, 583–592. https://doi.org/10.1134/S0016702919050057.
Liu, X., Lee Burras, C., Kravchenko, Y.S., et al., 2012. Overview of Mollisols in the world: distribution, land use and management. Can. J. Soil Sci. 92, 383–402. https://doi.org/10.4141/cjss2010-058.
Liu, Y., Wei, L., Luo, D., et al., 2021. Geochemical distribution and speciation of thallium in groundwater impacted by acid mine drainage (Southern China). Chemosphere 280, 130743. https://doi.org/10.1016/j.chemosphere.2021.130743.
López-Serrano, M.J., Velasco-Muñoz, J.F., Aznar-Sánchez, J.A., Román-Sánchez, I.M., 2020. Sustainable use of wastewater in agriculture: a bibliometric analysis of worldwide research. Sustainability 12, 8948. https://doi.org/10.3390/su12218948.
Maassen, S., 2016. Bibliometric analysis of research on wastewater irrigation during 1991-2014: bibliometric analysis of research on wastewater irrigation (1991-2014). Irrigat. Drain. 65, 644–653. https://doi.org/10.1002/ird.1981.
Makhkamova, D., Gafurova, L., Nabieva, G., et al., 2022. Integral indicators of the ecological and biological state of soils in Jizzakh steppe. Uzbekistan. IOP Conf Ser: Earth Environ Sci 1068, 012019. https://doi.org/10.1088/1755-1315/1068/1/012019.
Mei, Y., Ma, T., Su, R., 2021. How marketized is China's natural gas industry? A bibliometric analysis. J. Clean. Prod. 306, 127289 https://doi.org/10.1016/j.jclepro.2021.127289.
Melkonyan, A., 2015. Climate change impact on water resources and crop production in Armenia. Agric. Water Manag. 161, 86–101. https://doi.org/10.1016/j.agwat.2015.07.004.
Mkilima, T., Devrishov, D., Assel, K., et al., 2022. Natural zeolite for the purification of saline groundwater and irrigation potential analysis. Molecules 27, 7729. https://doi.org/10.3390/molecules27227729.
Montalván-Burbano, N., Pérez-Valls, M., Plaza-Úbeda, J., 2020. Analysis of scientific production on organizational innovation. Cogent Business & Management 7, 1745043. https://doi.org/10.1080/23311975.2020.1745043.
Murugappan, A., Manoharan, A., Senthilkumar, G., Krishnamurthy, J., 2017. Technical and sociological investigation of impacts in using lignite mine drainage for irrigation – a case study. IOP Conf. Ser. Earth Environ. Sci. 80, 012070 https://doi.org/10.1088/1755-1315/80/1/012070.
Nanekely, M., Al-Faraj, F., Scholz, M., 2023. Analysis of a joint impact of climate change and anthropogenic interventions on groundwater depletion in arid and semi-arid areas. In: Sherif, M., Singh, V.P., Sefelnasr, A., Abrar, M. (Eds.), Water Resources Management and Sustainability. Springer Nature Switzerland, Cham, pp. 167–203.
Nastasiuc, L., Bogdevici, O., Aureliu, O., et al., 2016. Monitoring water contaminants: a case study for the Republic of Moldova. Pol. J. Environ. Stud. 25, 221–230. https://doi.org/10.15244/pjoes/58888.
Nizhegorodtcev, E., Gerasimov, V., Svalova, K., 2022. Layer Drainage of Fibrous Materials in the Composition of the Ground Dams. https://doi.org/10.34910/MCE.110.1.
Norouzi Khatiri, K., Nematollahi, B., Hafeziyeh, S., et al., 2023. Groundwater management and allocation models: a review. Water 15, 253. https://doi.org/10.3390/w15020253.
Novikov, S.M., Goncharova, J.S., 1981. Forecasting changes of water resources in large rivers following land drainage/Méthode de prévision des modifications des ressources en eau des grands fleuves sous l'effet du drainage. Hydrol. Sci. Bull. 26, 393–398. https://doi.org/10.1080/02626668109490903.
Oglu Rzayev, M.A., 2007. Current irrigation system management features in Azerbaijan Republic. Irrigat. Drain. 56, 551–563. https://doi.org/10.1002/ird.324.
Okuda, Y., Onishi, J., Shirokova, Y.I., et al., 2020a. Water and salt balance in agricultural lands under leaching with shallow subsurface drainage used in combination with cut-drains. Water 12, 3207. https://doi.org/10.3390/w12113207.
Okuda, Y., Onishi, J., Shirokova, Y.I., et al., 2020b. Water and salt balance in agricultural lands under leaching with shallow subsurface drainage used in combination with cut-drains. Water 12, 3207. https://doi.org/10.3390/w12113207.
Persoone, G., Marsalek, B., Blinova, I., et al., 2003. A practical and user-friendly toxicity classification system with microbiotests for natural waters and wastewaters: toxicity Classification System with Microbiotests. Environ. Toxicol. 18, 395–402. https://doi.org/10.1002/tox.10141.
Pizzi, S., Caputo, A., Corvino, A., Venturelli, A., 2020. Management research and the UN sustainable development goals (SDGs): a bibliometric investigation and systematic review. J. Clean. Prod. 276, 124033 https://doi.org/10.1016/j.jclepro.2020.124033.
Pozdniakov, S.P., Pyu, Vasilevskiy, Wang, P., 2022. Analysis of a steady-state model of groundwater discharge in a river valley without and with evapotranspiration. Adv. Water Resour. 168, 104306 https://doi.org/10.1016/j.advwatres.2022.104306.
Qureshi, A.S., Eshmuratov, D., Bezborodov, G., 2011. Determining optimal groundwater table depth for maximizing cotton production in the Sardarya province of Uzbekistan. Irrigat. Drain. 60, 241–252. https://doi.org/10.1002/ird.568.
Radelyuk, I., Tussupova, K., Persson, M., et al., 2021. Assessment of groundwater safety surrounding contaminated water storage sites using multivariate statistical analysis and Heckman selection model: a case study of Kazakhstan. Environ. Geochem. Health 43, 1029–1050. https://doi.org/10.1007/s10653-020-00685-1.
Respondek, Z., 2019. Analysis of technical condition of local roads drainage in the czestochowa region. Quality Production Improvement - QPI 1, 251–260. https://doi.org/10.2478/cqpi-2019-0034.
Ryzhenko, B.N., Belova, T.P., Ryabenko, A.E., Cherkasova, E.V., 2016. Evaluation of acid drainage in ore deposits. Water Resour. 43, 957–966. https://doi.org/10.1134/S0097807816070125.
Sawassi, A., Khadra, R., 2021. Bibliometric network analysis of "water systems' adaptation to climate change uncertainties": concepts, approaches, gaps, and opportunities. Sustainability 13, 6738. https://doi.org/10.3390/su13126738.
Schirov, M., Legchenko, A., Creer, G., 1991. A new direct non-invasive groundwater detection technology for Australia. Explor. Geophys. 22, 333–338. https://doi.org/10.1071/EG991333.
Schubert, M., Michelsen, N., Schmidt, A., et al., 2021. Age and origin of groundwater resources in the Ararat Valley, Armenia: a baseline study applying hydrogeochemistry and environmental tracers. Hydrogeol. J. 29, 2517–2527. https://doi.org/10.1007/s10040-021-02390-4.
Seredin, V.V., Dai, S., 2012. Coal deposits as potential alternative sources for lanthanides and yttrium. Int. J. Coal Geol. 94, 67–93. https://doi.org/10.1016/j.coal.2011.11.001.
Shanin, V., Juutinen, A., Ahtikoski, A., et al., 2021. Simulation modelling of greenhouse gas balance in continuous-cover forestry of Norway spruce stands on nutrient-rich drained peatlands. For. Ecol. Manag. 496, 119479 https://doi.org/10.1016/j.foreco.2021.119479.
Sunkari, E.D., Adams, S.J., Okyere, M.B., Bhattacharya, P., 2022. Groundwater fluoride contamination in Ghana and the associated human health risks: any sustainable mitigation measures to curtail the long term hazards? Groundwater for Sustainable Development 16, 100715. https://doi.org/10.1016/j.gsd.2021.100715.
Thomas, H., Chen, Yun-Tai, Gasparini, Paolo, et al., 2011. OPERATIONAL EARTHQUAKE FORECASTING. State of knowledge and guidelines for utilization. Ann. Geophys. 54 https://doi.org/10.4401/ag-5350.
Tregubov, O.D., Glotov, V.E., Konstantinov, PYa, Shamov, V.V., 2021. Hydrological conditions of drained lake basins of the anadyr lowland under changing climatic conditions. GES 14, 41–54. https://doi.org/10.24057/2071-9388-2021-030.
van der Zee, S.E.A.T.M., Stofberg, S.F., Yang, X., et al., 2017. Irrigation and drainage in agriculture: a salinity and environmental perspective. In: Kulshreshtha, S., Elshorbagy, A. (Eds.), Current Perspective on Irrigation and Drainage. InTech.

Vander Wilde, C.P., Newell, J.P., 2021. Ecosystem services and life cycle assessment: a bibliometric review. Resour. Conserv. Recycl. 169, 105461 https://doi.org/10.1016/j.resconrec.2021.105461.

Velasco-Muñoz, J., Aznar-Sánchez, J., Belmonte-Ureña, L., López-Serrano, M., 2018. Advances in water use efficiency in agriculture: a bibliometric analysis. Water 10, 377. https://doi.org/10.3390/w10040377.

Xaliqulov, M., Kannazarova, Z., Norchayev, D., et al., 2023. Root harvester machine: a review of papers from the Scopus database published in English for the period of 1982-2022. E3S Web of Conf 402, 10010. https://doi.org/10.1051/e3sconf/202340210010.

Xiong, H., Wang, Y., Guo, X., et al., 2022. Current status and future challenges of groundwater vulnerability assessment: a bibliometric analysis. J. Hydrol. 615, 128694 https://doi.org/10.1016/j.jhydrol.2022.128694.

Yang, F., Jia, C., Yang, H., Yang, X., 2022. Development, hotspots and trend directions of groundwater salinization research in both coastal and inland areas: a bibliometric and visualization analysis from 1970 to 2021. Environ. Sci. Pollut. Res. 29, 67704–67727. https://doi.org/10.1007/s11356-022-22134-5.

Zaidel'man, F.R., 2011. The problem of fire control on drained peatlands and its solution. Eurasian Soil Sci. 44, 919–926. https://doi.org/10.1134/S1064229311080175.

Zegeye, A.D., Fentahun, M., Alemie, T.C., Amare, T., 2021. A low-cost subsurface drainage technique to enhance gully bank stability in the sub-humid highlands of Ethiopia. J. Hydrol. Hydromechanics 69, 311–318. https://doi.org/10.2478/johh-2021-0019.

Zekster, I.S., 1995. Groundwater discharge into lakes: a review of recent studies with particular regard to large saline lakes in central Asia. Int. J. Salt Lake Res. 4, 233–249. https://doi.org/10.1007/BF02001493.

Zektser, I.S., Dzhamalov, R.G., 1981. Groundwater discharge to the Pacific Ocean/Apports des eaux souterraines à l'Océan Pacifique. Hydrol. Sci. Bull. 26, 271–279. https://doi.org/10.1080/02626668109490886.

Zektser, I.S., Loaiciga, H.A., 1993a. Groundwater fluxes in the global hydrologic cycle: past, present and future. J. Hydrol. 144, 405–427. https://doi.org/10.1016/0022-1694(93)90182-9.

Zektser, I.S., Loaiciga, H.A., 1993b. Groundwater fluxes in the global hydrologic cycle: past, present and future. J. Hydrol. 144, 405–427. https://doi.org/10.1016/0022-1694(93)90182-9.

Zhang, G., Xie, S., Ho, Y.-S., 2010. A bibliometric analysis of world volatile organic compounds research trends. Scientometrics 83, 477–492. https://doi.org/10.1007/s11192-009-0065-3.

Zhang, X., Guan, T., Zhou, J., et al., 2018. Groundwater depth and soil properties are associated with variation in vegetation of a desert riparian ecosystem in an arid area of China. Forests 9, 34. https://doi.org/10.3390/f9010034.

Zvereva, V.P., Frolov, K.R., Lysenko, A.I., 2022. Formation of mine drainage in the Far Eastern region and its impact on the ecosphere and public health. Min. Sci. Technol. 7, 203–215. https://doi.org/10.17073/2500-0632-2022-3-203-215.