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Title

Discovering research trends of urban geology based on a bibliometric analysis

Abstract

Urbanization contributes to the emerging of urban areas across the world. The importance of geology to assure sustainability has led to many research publications in urban geology. This paper aims to discover the research trends through a bibliometric analysis of articles indexed within the Scopus database from 1950 to 2018 (as of the end of July) on topics related to geology and urban. The analysis found a significant increase in publication number during 1999-2016, especially after the 2004 Indian Ocean earthquake and tsunami disaster. The next finding is related to research interest clusters: (1) engineering geological hazard investigation and risk assessment in the urban area (EGR); (2) social geology and urban sustainability (SGS); and (3) urban hydrology and water management (HGW). Research gap found issues on EGR majored in underground civil planning (geotechnics) received more attention from researchers. In contrast, the least attention is on the geology and land use planning, under the SGS issues. This study may serve as a platform for scholars to understand the current status and future directions of urban geology.

Keywords

Bibliometric; urban geology; environmental geology; engineering geology; urban planning

1. Introduction

Amount of research publications in the field of geology has reached an enormous number. A broad search using Scopus search facilities to research articles that include geology as a keyword resulted in at least 120,000 documents, exploring more than 25 subject areas. As the public viewed geology as likely identic to mining and petroleum, these topics indeed dominate about 45% of the total searched documents. Mining and oil commonly described geology in the less-populated area. However, the rest topics (± 55%) show how geology is applied in the more-populated area (urban area). It is later known as urban geology, which is less popular among societies, although many people have been benefited from it.

Urban geology began to grow in the 1950s after World War II in the United States of America, particularly in California, concerning land-use planning due to tremendous economic growth and urban expansion [1, 2, 3]. Intense meeting sessions discussed on urban geology were held in the 1960s and into the 1970s [4, 5], and soon followed by the publication of the book 'Cities and Geology' [6]. As more and more the world's population already live in urbanized areas (>50%) as in developing countries, migration to urban areas is increasing [7, 8], it brings significant challenges for urban areas since there is increased pressure on resources, spaces, and services [8,9]. For example, the zones now available for constructions are usually the least suitable ones. Whereas, neglect of its geological structure potentially leads to severe economic loss. Therefore, geology plays a critical part in ensuring sustainable cities. What will happen when a proper geological investigation does not carry out in planning? Meanwhile, how great the benefit can be obtained when accomplished appropriate geological studies? [6].

As a result, today, urban geology has become an essential part of engineering geology [1], whereas it should go beyond that [10].

Even though the value of urban geology is not fully appreciated by those charged with the management and improvement of the world's cities. It was maybe because engineering geologists have failed to show the benefits of geological applications in terms of cost and urban environmental improvement [1]. In turn, academic research on urban geology keeps growing, and the number of papers has been published enormously. Unfortunately, the existing literature ranging in too broad topics, makes it difficult to derive the research trends on urban geology. Therefore, a better analysis of articles published in academic journals would assist researchers and practitioners in exploring the current status and future direction in this particular area [11].

Between 1970 and 1988, few organizations (e.g., Association of Environmental and Engineering Geologists (AEG), Economic and Social Commission for Asia and the Pacific (ESCAP), Geological Association of Canada) published a few books volume on the urban geology. Limited papers presented in that works were short case histories on the urban or engineering geology of individual cities [1]. In different, this paper presents most of the research literature on urban geology. It is aimed to discover the research trends of urban geology based on bibliometric analysis, and extended to answer the following questions:

1. What was the annual publication trend of urban geology-related researches from 1950 to 2018?
2. What was the research topics interest of urban geology from 1950 to 2018, and how did these research topics interest interact with each other?
3. What is the gap in the current research trend?

The term bibliometric refers to applying a quantitative method to evaluate research within the scientific and applied field [11, 12]. Bibliometric analysis has become a mature tool and essential in research to detect areas for further research and strengthen research capacity in the future without bias upon existing research works [11, 13]. This kind of analysis has been conducted for various purposes [e.g., 14, 15, 16]. This study, however, among the first to adopt this bibliometric analysis in the context of urban geology researches.

The structure of this paper is as follows. The first section presents the rationale, aim, and objectives. The second section outlines the research method. The main research findings are discussed in section three, including a discussion on the recommendation for future studies. The last section summarizes the conclusions. Finally, it is hoped that this paper will be useful to any community to gain a broader perspective in urban geology.

2. Methods

2.1 Keywords approaches and framework

The term urban geology (UG) has been defined in various ways. Table 1 presents the sequence of urban geology definitions between 1950 to 2018 in the literature. Some different definitions say the same thing but in different words. This fact has led to the formulation of a group of preferred key concepts for urban geology that correlate with each other.

From the definitions, it is clear that the terms urban geology, environmental geology, and engineering geology are interchangeably used [2,18,19]. While the term urban is interrelated with the concept of the city [20]. The city is a settlement that administratively delimited, altogether with the concentration of buildings, roads, public and private spaces, people, conflicts, and common efforts [18, 19]. According to Frey and Zimmer [20], urban (area) has always performed a wide range of city functions. It is a settlement with a high population (where a significant majority of the population is not primarily engaged in agriculture, or where there is surplus employment), expand beyond administrative boundaries, and include cities, towns even suburb [20, 21].

Moreover, the term city is frequently used to describe a metropolitan area, region, and urban agglomeration [25]. The Metropolitan area comprises the urban space as a whole and its primary commuter [26], typically formed around a city with a large concentration of people (i.e., a population of at least 1,000,000). On a larger scale, an urban agglomeration with 10 million or more called a megacity [27]. These definitions suggest that the terms city (cities), urban, metropolitan (area), and megacity are interchangeable, depends on its setting context.

<Table 1>

The preferred key concepts column (Table 1) also shows how the urban geology definition is often approached by the concept of urban planning and development [4, 25, 26, 27, 28]. Urban planning is the organized planning of the physical environment on where the human lives to create healthy, reliable, and durable living spaces by providing safety in line with the social, cultural, and economic needs [31]. Earth science factors (e.g., geology) are essential in planning for urban development initiatives. These factors embrace ground-related problems and other potential constraints to development [32]. The use of geology for urban planning and development has been applied in a natural hazard environment [e.g., 31, 32], seismic environment [e.g., 33, 34], geotechnics or engineering cases [e.g., 35, 36, 37], and potential suitability assessment [33,40]. Also, the XII International IAEG Congress 2014 in Torino has initiated the publication of a book series as part of its proceedings entitled ‘Engineering Geology for Society and Territory - Volume 5: Urban Geology, Sustainable

Planning and Landscape Exploitation' [41]. For instance, at present, the needs of geology in planning and development in the urban area are expected to increase due to the rapid growth of its population.

2.2 Multi-stage data processing

The journal articles related to urban geology between 1950 and 2018 were searched in the Scopus database on July 24th, 2018. Scopus was selected because it has the largest single abstract and indexing database [42]. Scopus also leads as citation sources to journal papers compare to other bibliometric data collection tools [43].

The selection method comprises three stages. First, the combination of few queries of keywords using Boolean operators such as "AND", "OR", and "NOT" in Scopus search analysis. The selection of keywords was formulated from the key concepts, as appeared in various definitions of urban geology, as explained in the previous section. The first query is *"urban geology"* which resulted in 167 documents. The use of quotation marks ("_") is to search for the exact phrase as it appears in the papers. The second query is *environmental AND geology** resulted in 14,087 documents. The * symbol is used to search for an alternate word ending, while AND is used to combine the phrase searching without it becomes an exact phrase. It means the search results may be from documents containing the word 'environmental' only or 'geology' only or both words 'environmental geology'. The third query is *engineering AND geology** resulted in 25,303 documents. The fourth query is a combination of *geolog* AND urban OR city OR cities OR metro* OR megacit* AND planning OR development* resulted in 4,798 documents. Again, here some key concepts were truncated using the * symbol to expect variant endings at the end of a word searched (e.g., megacities, megacity for megacit*). OR is used to combine related terms or synonym from urban (i.e. city, cities, metropolitan, megacity). All four queries are thus stored in the search history. In final, this stage combined all four queries as #1 OR #2 OR #3 AND #4. Sets of queries were combined using "OR" and "AND". This combined stage gave 1478 documents. However, these results may include some irrelevant publications that meet the searched keyword but not related to urban geology (UG).

The second stage involves excluding document type, languages, and subject areas that are not directly related to urban geology. First, limit the search to the article type only. The search results were 735 documents. Later only articles in the English language were filtered, resulted in 595 papers. The search was further excluded from the subject areas such as "medical," "physics," "business," "economy," "arts," "decision policy," "chemical engineering," "chemistry," "material," "mathematics," "immunology," "nursing," "pharmacy," "psychology," "energy," and "computer". This stage give 529 documents left.

The third stage involves exclusion on any topics that are too broad-based on title, abstract, author keywords, and index keywords. Results from the previous step were downloaded in PDF format. Type of information, i.e. citation information and abstract, author, and index keywords, were included when downloaded into PDF. Hence, to ensure the relevant content, the abstracts in the PDF format were scanned by reading each abstract of the 529 research articles to determine exclusion from the results further. In the final, there were 285 articles selected. The summarize of the three stages, and its refining results are shown in Table 2.

<Table 2>

2.3 Data analysis

In the analytical phase, the number of 285 research articles were analyzed in terms of amounts and time of publications, keywords, topics, and sub-topics. The authors used the Scopus feature, such as the metric article module, to analyze the annual publication trend statistically.

However, in observing the research trends, the authors used the clustering technique, which is available in a free software tool, VOSviewer. Clustering by VOSviewer was done based on the fractional-counting method on the keywords relations between the clusters. Visualization presented each set in color (i.e., red, blue, or green) that indicates the group in which the cluster was mapped [44]. The clusters were analyzed further to answer the research questions.

3. Results and discussions

3.1 Annual publication trend of urban geology-related researches

The distribution of articles by publication in urban geology (UG) research per year is shown in Figure 1. Although the search timeline was set from 1950 (the year when the UG topic began to grow) until 2018, in fact, the years in which publications were found ranges from 1970 to 2018. However, Figure 1 shows a leveling off in the number of publications during 1970-1981 and a slow increase in numbers of publications from 1982 to 1997. A significant increase was observed during 1999-2016, as the number of research articles increased from 9 to 17. Out of the 285 analyzed articles, only one was published in 1998, but the 187 articles were published in the 2000s. It could be easily explained by the fact that global research declined (including research in UG's field) as the Asian financial crisis hit in 1997-1998. However, the UG concept emerged in the 2000s, especially after the 2004 Indian Ocean earthquake and tsunami disaster regarding urban resilience.

<Figure 1>

3.2 Research topics interest in urban geology

The research questions such as, "What was the research topic interest of UGs from 1950 to 2018?" and "How did these research topics interest interact with each other?" were answered by the authors by constructing a co-occurrence map based on bibliographic data by the VOSviewer software. All keywords were divided into clusters for the data selection and thresholds, the minimum number of occurrences of all keywords set at 15. Among the 2688 keywords, 42 met the threshold and presented as 42 nodes. As suggested by Eck and Waltman [45] in constructing the bibliographic coupling networks, the authors applied VOSviewer's fractional counting methodology instead of the ordinary full counting one. Hence, all publications will have the same portion of counting [45]. The processed bibliographic data, as mentioned, is available online at https://bit.ly/3g9FFDK.

<Figure 2>

The processing resulted in the keywords were grouped into three clusters as visualized by the VOSviewer in Figure 2. The three clusters represented by three different colors, in which green represents cluster 1, red represents cluster 2, and blue represents cluster 3. The nodes in Figure 2 represent a term, and the node's distance reflects the relation among them. The closer the nodes means the more intensive relationship between the two terms. This intensive relationship was later explained as a link strength. The term which has a higher weight, which is means a higher number of occurrences, is represented as a larger node. A summary of the clusters and terms is shown in Table 3.

Each term is connecting to other terms by a link line showing the relation between the two terms. The stronger the link, the thicker the line in display [46]. All terms are quantified according to their occurrences and link strength, as shown in Table 4. The link strength is indicating how strong the relationship between the two terms, and the total link of the node means the sum of link strengths of this particular node over all other nodes [47]. As we can see in Figure 2, there are several significant nodes on the map from which indicate the most common terms. They are “Engineering geology”, “Geology”, “Urban planning", and “Urban area”. These four terms covered in cluster one and two but left out the cluster three without any significant node.

<Table 3>

The following sub-section outline the three clusters representing the three research topics interest – they are engineering geological hazard investigation and risk assessment in the urban area (EGR); social geology and urban sustainability (SGS); and urban hydrology and water management (HGW). In general, there are more researches on the topic of EGR (42%), followed by those on SGS (33,7%) and HGW (24,3%).

<Table 4>

3.2.1 Cluster 1 - Engineering geological hazard investigation and risk assessment in the urban area (EGR)

The green cluster (cluster 1) contains 14 nodes in which the keyword "Engineering geology" has the highest occurrence and total link strength. The node engineering geology display thick lines connecting with almost all terms in all clusters figured out the fact of how urban geology researches mostly related to engineering geology. Other prominent terms in this area include "Geotechnical engineering", "Subsidence", "Eurasia", and "Hazard assessment" (Figure 3).

There are 120 articles in this cluster. The articles are mostly related to hazard investigation and risk assessment on the underground civil planning (geotechnics), karst collapse and subsidence, landslide, seismic evidence for earthquake, and general geological hazard cases. All cases were viewed from the perspective of engineering geology.

Almost half of the EGR research articles focus on underground civil planning (geotechnics) cases in an urban area (47%). The most popular topic such as tunnelling [48, 49, 50, 51], underground spaces [52, 53, 54], and geotechnics modelling [56, 57, 58, 59]. Case studies for these topics mostly taken places on developed countries such as the USA (e.g., Los Angeles, New York, San Francisco, Boston), Japan (Tokyo), Canada (e.g., Metro Toronto, Ontario, Saskatchewan), United Kingdom (London), The Netherland, Singapore, etc.

The next most significant focus of the EGR articles being studied in a row are karst collapse and subsidence cases (14%), seismic evidence for earthquake cases (13%), landslide cases (12%), and other types of geohazards cases in general (10%). Research on karst collapse and subsidence were mostly taken place on issues in European countries such as Italy, Spain, and Belgium [59, 60, 61]. While for landslide, the related topics are land use and landslide [62, 63], landslide vulnerability and risk assessment [64, 65, 66]. Other issues related to seismic evidence for earthquakes [67, 68, 69, 70] are mostly situated on earthquake hazard cases in Turkey's urban area. Eurasian Plate movement was most frequently discussed in these earthquake hazard cases. Some researchers also studied the engineering geological hazard investigation and risk assessment in general from all possible aspects in the urban area, including about heritage building stones conservation [71, 72, 73].

<Figure 3>

The oldest publication listed in this cluster is the one written by an Indonesian author [74]. It studied the application of engineering geology in Indonesia for specific purposes, including for regional development and urban geology, concerning previously engineering geology in Indonesia only contributed, first, as geologic advice in large civil engineering construction projects and two, in the increase of human resources. Unfortunately, no citation was recorded for this paper [75]. This might suggest that the initial idea of engineering geology as part of urban geology in Indonesia did not well followed up. However, there are a small number of papers in this cluster related to volcanic eruptions [76], flood [77], and building stones decay and preservation [78] (Figure 4).

<Figure 4>

3.2.2 Cluster 2 - Social geology and urban sustainability (SGS)

Cluster 2 was represented by red color containing 14 nodes in which the five highest weight and total link strength keywords are "Urban planning", "Urban area", "Land use", "Urban development", and "GIS" (Figure 5). However, as indicated by "Environmental geology" as the closest node with “Urban planning” and a very thick line between “Geology” and “Urban planning” figured out how urban planning and geology are interrelated in common in the domain of environmental geology.

There are 96 articles in this cluster. This cluster is on the topic of SGS. The term social geology refers to the discipline of geology that studies the interaction between the geological environment and the social development, especially the influence of geological resources and risks on the territorial and social management of urban zones [79]. SGS includes geo-environmental appraisal in developing urban areas. It is ranging from urban geology mapping for land use planning purposes (56%), GIS-based geo-environmental suitability assessment for urban land use planning (20%), environmental monitoring, assessment, and landscape management (13%), monitoring, policy, and law for urban planning (11%).

<Figure 5>

The topic that has received the most attention in this SGS cluster is related to urban geology mapping for land use planning purposes [80, 81, 82, 83, 84]. The significant period of these 52 publications in this topic was before the 2000s then reduced slightly. It was before GIS (Geographic Information System) studies well-developed and applied. Since the early 2000s, mapping for urban land use planning is no longer by field geological investigation but accompanied by GIS approach. GIS-based geo-environmental suitability assessment for urban land-use planning has been the second majority topic in this cluster [85, 86, 87, 88]. Most of the GIS approach in the study collaborated with AHP (Analytic Hierarchy Process) method. It is tally with the finding in a paper [89] in the context of geology for urban land use planning studies, particularly in Indonesia. The third majority topic in this cluster is related to the environmental monitoring and assessment [90, 91, 92], and the least is the topic connected to monitoring, policy, and law for urban planning [93, 94, 95] (Figure 6).

<Figure 6>

3.2.3 Cluster 3 - Urban hydrology and water management (HGW)

The third cluster is related to HGW. It is (labeled as blue color) consisted of 14 nodes in which almost all terms containing “water” as part of the keyword (Figure 7). The most frequent relevant terms that appeared and linked are “Storm sewers”, “Runoff”, “Stormwater”, and “Flood”. Stormwater is rainwater that extremely runoff from land or built-up surfaces such as roofs, driveways, pavements, footpaths, and road infrastructures where water cannot penetrate [96]. The common issues regarding stormwater are stormwater pollution and flood. One of the best management practices to control stormwater pollution is developing its sewer system called storm sewer, expected to be different from wastewater sewer [97]. Moreover, storm sewers can be a solution to reduce floods by minimizing the discharge rate from urban catchment areas [98]. The discussion is part of urban water (hydrology) management, closer to the domain of civil or environmental engineering instead of geology.

<Figure 7>

There are 69 articles in the cluster (Figure 8). About 49% of articles focused on stormwater management (including flood assessment and modeling, urban stormwater, and storm sewer). The second focus in the cluster is articles on wastewater treatment, including water quality and geochemistry (31 %). However, there are a small number of articles focused on groundwater (20 %). The last focus mentioned is the only match with geology [99, 100, 101, 102].

<Figure 8>

3.3 Research gaps and future studies

This section is focused on pointing gaps in the existing research trend and recommendations related to future studies. *First*, the increasing trend of UG research during the past 40 years is in line with urbanization. However, the emerging trend moves slowly before the 2000s but surely afterward. To be then, it needs something to come up as a trigger, such as the 2004 Indian Ocean earthquake and tsunami event that was killing thousands of people who live in an urban area. The initiation of Sustainable Development Goal (SDGs) in 2015 engaging geologists to play a role in helping and ensuring sustainable foundations for future global development. Among the agreed geological aspects in SDGs [103] that tally with this study are engineering geology, geohazard, hydrogeology, and geo-heritage. Since then, many UGs articles were trying to relate their studies to the sustainable development concept [e.g., 72, 104, 105]. The research and application of UGs have, therefore, been postulated as a promising approach for sustainable development goals, especially for the 11th goal – sustainable cities and communities. It is expected that UG research will be increasingly popular among researchers in the future.

Second, it is found there are more research articles on EGR than on SGS and HGW topics. The majority of current research mainly focused on engineering geology related to hazard investigation and risk assessment for underground geotechnics construction. The majority of underground geotechnics research focused on case studies in developed countries, specifically in the Metropolitan area, such as New York, San Francisco, Tokyo, Toronto, London, Singapore, etc. It is because the demand for underground infrastructure as solutions for traffic and utilities is growing in Metropolitan cities. Those related to natural hazards such as subsidence, landslide, and earthquake in urban areas have also received attention recently, but still, they were viewed from an engineering geology perspective. In the future, it would be interesting to explore and examine the influence and barriers of UG in developing countries.

The *third*, as shown in Table 4, the term "land use planning" has the lowest link strength among all other mapped terms from the whole three clusters. Among other terms which have lower link strength are planning and sustainable development. It indicates the most significant gap in UG studies is the interaction between the geology and the land use planning studies, under the umbrella of social geology and urban sustainability (SGS). It was also indicated that sustainable cities and the community have not yet considered geology in measuring a successful goal. Approach methods using GIS and AHP or even SMCE can be elaborated still in the future studies of geology for urban land use planning.

The *fourth* discussion on the flood hazard and urban hydrogeology in this paper were minimal. Urban water-related articles which are covered in UG topics were mostly discussed in term of quantitative water management, storm sewer, and stormwater pollution, which is not fit in the scope of geology but civil engineering. Some articles on the influence of geological setting to problems associated with flooding and groundwater supply in an urban area indeed appeared before the 2000s. However, the needs of necessary geological information on the water condition (either groundwater or surface water) nowadays are elaborated for answering practical hydrogeologic management and engineering questions. It is as expected as hydrogeologic science is not well suited to quantitative prediction, but best suited for providing theoretical and basic science which can be applied when suggesting solutions to complex practical problems [106].

4. Conclusions

As presented in this paper, the bibliometric analysis offered an effective way to obtain the answer to the trend and gaps in UG research around the world during the years 1970-2018. The help of clustering software VOSviewer effectively reduced biases in topics classifying and networking.

The term UG has been developed in an incredible milestone. Firstly appearing in the 1970s as cited in [74], it is defined as engineering geology appraisal for urban planning. UGs further applied beyond engineering geology and civil engineering. It is emerging as the application of the Earth sciences to any problems arising within urban areas. Urban geology supports the idea that human impacts the landscape [10]. Therefore, the UG topic is always accompanied by keywords such as engineering geology, environmental geology, landscape, urban, city, planning, and development.

A total of 285 UG-related papers were analyzed in this study. The three topics of engineering geological hazard investigation and urban risk assessment, social geology and urban sustainability, and urban hydrology and water management have been expanded to detail sub-topics, including (1) underground geotechnics, (2) karst collapse and subsidence, (3) landslide, (4) earthquake, (5) building stones conservation, (6) general engineering geological hazard cases, (7) urban geology mapping for land use planning, (8) GIS-based geo-environmental suitability assessment for urban land use planning, (9) environmental monitoring, assessment, and landscape management, (10) monitoring, policy and law for urban planning, (11) stormwater management, (12) wastewater treatment, and (13) groundwater. Summary of these research interests has provided an overview of the development of UG's in the academic field as a platform for scholars to continue developing the trend or to explore a new direction in urban geology.

Although the objectives of this study were achieved, results may include some limitations. The limitation is related to data sets collection. Ideally, bibliometric analysis comprising data sets from Scopus, Web of Science, and Google Scholar should have been done to increase the sample size (number of papers) [107]. Therefore can reflect a more comprehensive research trend instead of focused solely on the information provided from Scopus.

Data (and Software) Availability

Data are extracted from Scopus database, using the keywords described in Method section. VosViewer is available from vosviewer.com, created by Centre for Science and Technology Studies, Leiden University, The Netherlands.

Author Contributions

- DEI conceived the idea, designed the experiments, analyzed the results and drafted the paper.
- YU and RMP performed the experiments, analyzed the results and interpreted the data; wrote the paper.
- BK and DJP: analyzed and interpreted the data, and wrote the paper.

Competing Interests

The authors declare no conflict of interest.

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Supplementary Material

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Additional information

No additional information is available for this paper.

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Figures and Tables

Table 1. Various definitions of urban geology in sequence years. Each definition is accompanied by selected preferred key concepts, which are later a combination of these key concepts become keywords to filter literature in the Scopus database.

Year	Definitions	Preferred key concepts
1970	"Urban geology in the modern context is considered to be a close synonym for environmental geology" [18]	urban geology; environmental geology
1988	"Urban geology is the application of geological knowledge of urban areas to the solution of engineering geological problems" [5]	urban geology; engineering geology; urban areas
1992	"Urban geology considered as the field of applied geology that deals with major population centers and covers parts of engineering geology, environmental geology, and land management, where geotechnics (rock-/soil mechanics) and geohydrology disciplines are of major importance in urban geology" [2]	urban geology; engineering geology; environmental geology; land management
1994	"Urban geology is the study of land resources and geologic hazards related to the development, redevelopment, and expansion of urban areas. It focuses not only on the study of the physical environment on which the city is located but also on the prediction of its changes under the influence of human engineering and economic activities, provided for those responsible for urban planning and decision making from the viewpoint of engineering geology" [30]	urban geology; development; expansion; urban areas; city; urban planning; engineering geology
2005	"Whether it is called urban geology or environmental geology, there has always been a need for the study of how geology affects cities development" [19]	urban geology; environmental geology; city; cities; development
2006	"Urban geology means integrating surface and sub-surface geoscientific information for development needs" [29]	urban geology; development
2007	"Urban geology is the application of geologic knowledge to the planning and management of metropolitan areas" [28]	urban geology; planning; management; metropolitan area
2011	"Urban geology is the study of the interaction of human and natural processes with the geological environment in urbanized areas and the resulting impacts, and the provision of the necessary geo-information to enable sustainable development, regeneration and conservation" [1]	urban geology; geological environment; urban areas;
2011	"Urban geology provides information required for sound urban planning and sustainable development in densely populated areas" [4]	urban geology; urban planning; development
2015	"Urban geology focuses on monitoring using remote sensing; data, mapping, and modeling; and geohazards in the urban environment" [41]	urban geology; geohazards; urban environment
2016	"Urban geology is the application of the earth sciences to problems arising at the nexus of the geosphere, hydrosphere, and biosphere within urban and urbanizing areas, where it goes beyond the application of geology in civil engineering (commonly called engineering geology) and draws on the entire toolbox of the earth sciences, from stratigraphy to	urban geology; urban areas; engineering geology; environmental science

	geochemistry and hydrogeology to geophysical exploration techniques, linking to the biological and environmental sciences” [10]	

Table 2. Stage processes for inclusion and exclusion criteria for search terms

Stage	Inclusion/ exclusion	Description	Search terms	Results
First	Inclusion based on search terms	Keywords	(TITLE-ABS-KEY (“urban geology”)) OR (TITLE-ABS-KEY (environmental AND geology*)) OR (TITLE-ABS-KEY (engineering AND geology*)) AND (TITLE-ABS-KEY (geolog* AND urban OR city OR cities OR metro* OR megacit* AND planning OR development))	1478
Second	Exclusion on document type	Only journal articles are included	AND (LIMIT-TO (DOCTYPE, “ar”))	735
	Exclusion on language	Only journal articles written in English are included. Those are written in other languages are excluded.	AND (LIMIT-TO (LANGUAGE, “English”)) AND (EXCLUDE (LANGUAGE, “French”) OR EXCLUDE (LANGUAGE, “German”) OR EXCLUDE (LANGUAGE, “Italian”) OR EXCLUDE (LANGUAGE, “Persian”) OR EXCLUDE (LANGUAGE, “Spanish”) OR EXCLUDE (LANGUAGE, “Croatian”) OR EXCLUDE (LANGUAGE, “Finnish”))	595
	Exclusion on the subject area	Those that are too broad on the subject area are excluded	AND (EXCLUDE (SUBJAREA, “MEDI”) OR EXCLUDE (SUBJAREA, “BUSI”) OR EXCLUDE (SUBJAREA, “PHAR”) OR EXCLUDE (SUBJAREA, “CENG”) OR EXCLUDE (SUBJAREA, “CHEM”) OR EXCLUDE (SUBJAREA, “MATE”) OR EXCLUDE (SUBJAREA, “BIOC”) OR EXCLUDE (SUBJAREA, “PHYS”) OR EXCLUDE (SUBJAREA, “ECON”) OR EXCLUDE (SUBJAREA, “ARTS”) OR EXCLUDE (SUBJAREA, “DECI”) OR EXCLUDE (SUBJAREA, “IMMU”) OR EXCLUDE (SUBJAREA, “MATH”) OR EXCLUDE (SUBJAREA, “MULT”) OR EXCLUDE (SUBJAREA, “NURS”) OR EXCLUDE (SUBJAREA, “PSYC”) OR EXCLUDE (SUBJAREA, “ENER”) OR EXCLUDE (SUBJAREA, “COMP”))	529
Third	Exclusion based on citation information, abstract, and keywords.	Those that are too broad on the subject area are excluded	Transfer to PDF. Topics that are too broad-based on title, abstract, author keywords, and index keywords manual review	285

Table 3. Summary of the three mapped clusters

Cluster	Number of terms	Terms
1	14	China; engineering geology; Eurasia; geology; geomorphology; geotechnical engineer; groundwater; hazard assessment; hazards; hydrogeology; mapping; planning; soils; subsidence
2	14	Environmental geology; Geographic Information System; geological mapping; G.I.S.; land use; land use planning; risk assessment; sustainable development; United States; urban area; urban development; urban geology; urban growth; urban planning
3	14	Article; environmental impact; floods; hydrology; rain; runoff; storm sewers; storms; stormwater; urbanization; water management; water pollution; water quality; water supply

Table 4. Detail description of terms with the most significant link strength accordingly

Terms	Total link strength	Weight	Cluster	Terms	Total link strength	Weight	Cluster
Engineering geology	81.00	88	1	Geotechnical Eng.	20.00	21	1
Geology	77.00	84	1	Urban geology	20.00	20	2
Urban planning	55.00	63	2	Risk assessment	18.00	18	2
Urban area	53.00	53	2	Soils	18.00	19	1
Land use	36.00	37	2	Geological mapping	18.00	19	2
Urban development	35.00	36	2	Water supply	18.00	18	3
GIS	32.00	34	2	Urban growth	18.00	18	1
Groundwater	26.00	27	1	Water management	18.00	18	3
Eurasia	26.00	26	1	Hazards	18.00	18	1
Storm sewers	24.00	24	3	Hydrogeology	17.00	17	1
Urbanization	24.00	24	3	China	17.00	18	1
Storms	23.00	23	3	Subsidence	16.00	16	1
Article	22.00	22	3	Mapping	15.00	15	1
Geog. Information Syst.	22.00	22	2	Rain	15.00	15	3
Environmental impact	22.00	22	3	Floods	15.00	15	3
Runoff	21.00	21	3	Water pollution	15.00	15	3
Environmental geology	21.00	23	2	Water quality	14.00	15	3
Geomorphology	20.00	20	1	Sustainable dev.	14.00	15	2
Stormwater	20.00	20	3	Hydrology	14.00	15	3
Hazard assessment	20.00	20	1	Planning	14.00	15	1
United States	20.00	20	2	Land use planning	13.00	15	2

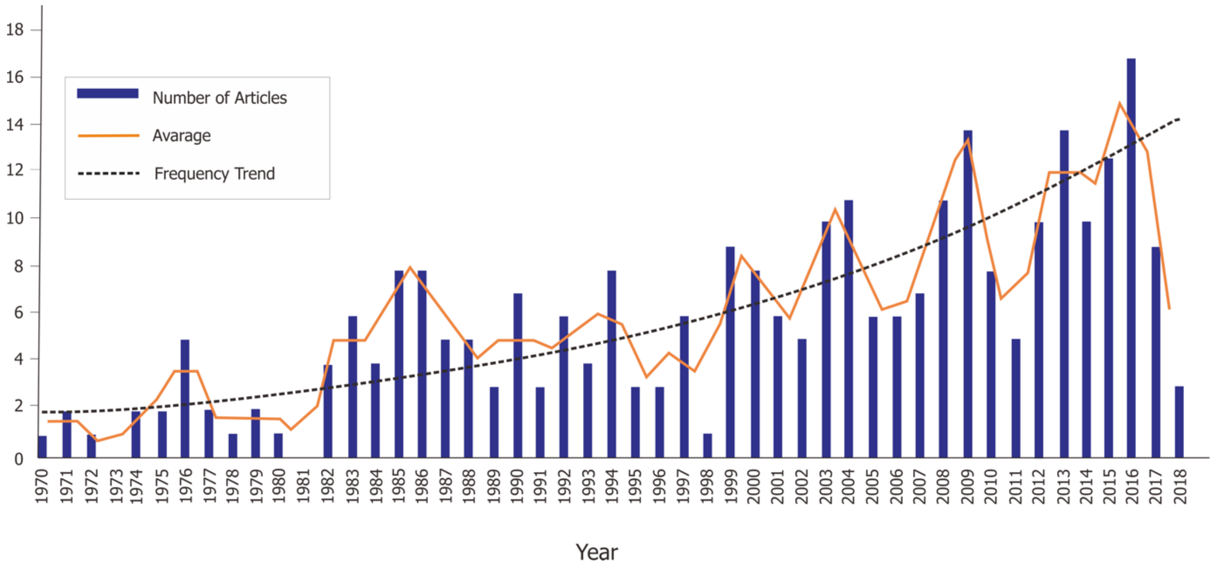

Figure 1. Annual urban geology research publication trend from 1970 to 2018 (as of the end of July).

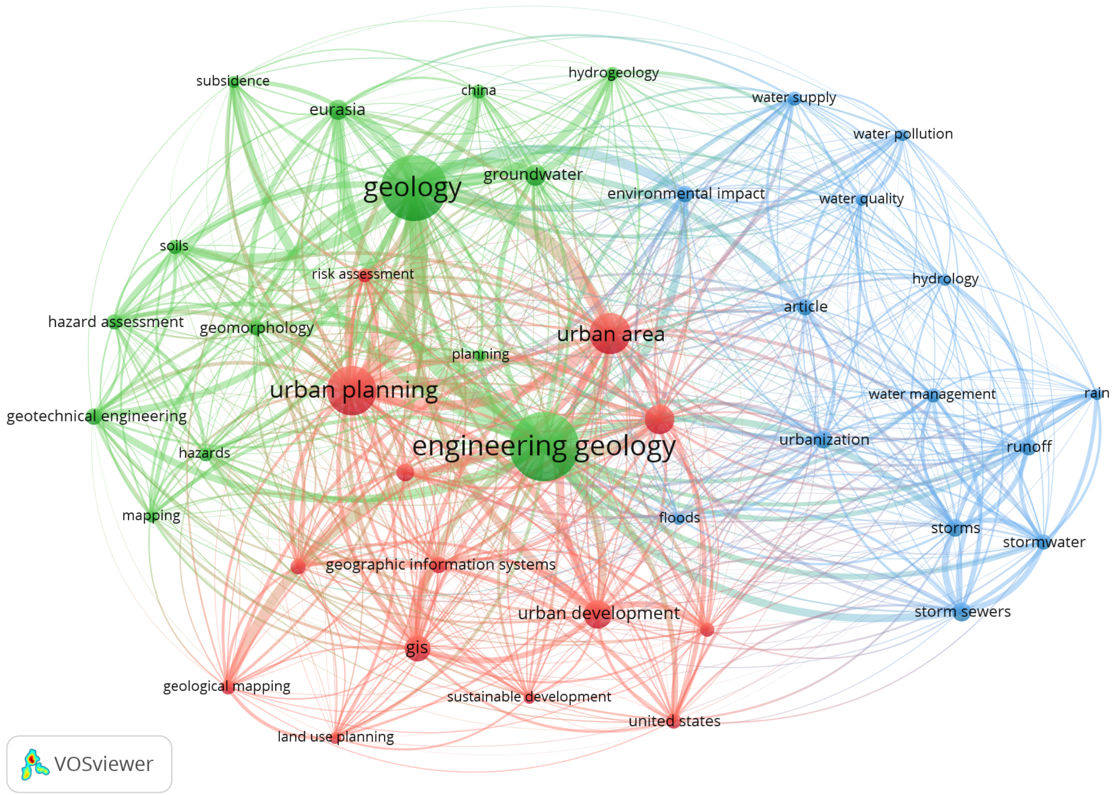

Figure 2. VOSviewer keywords co-occurrence map. The visualization shows 42 terms to which belong to cluster 1 (green color), cluster 2 (red color), and cluster 3 (blue color).

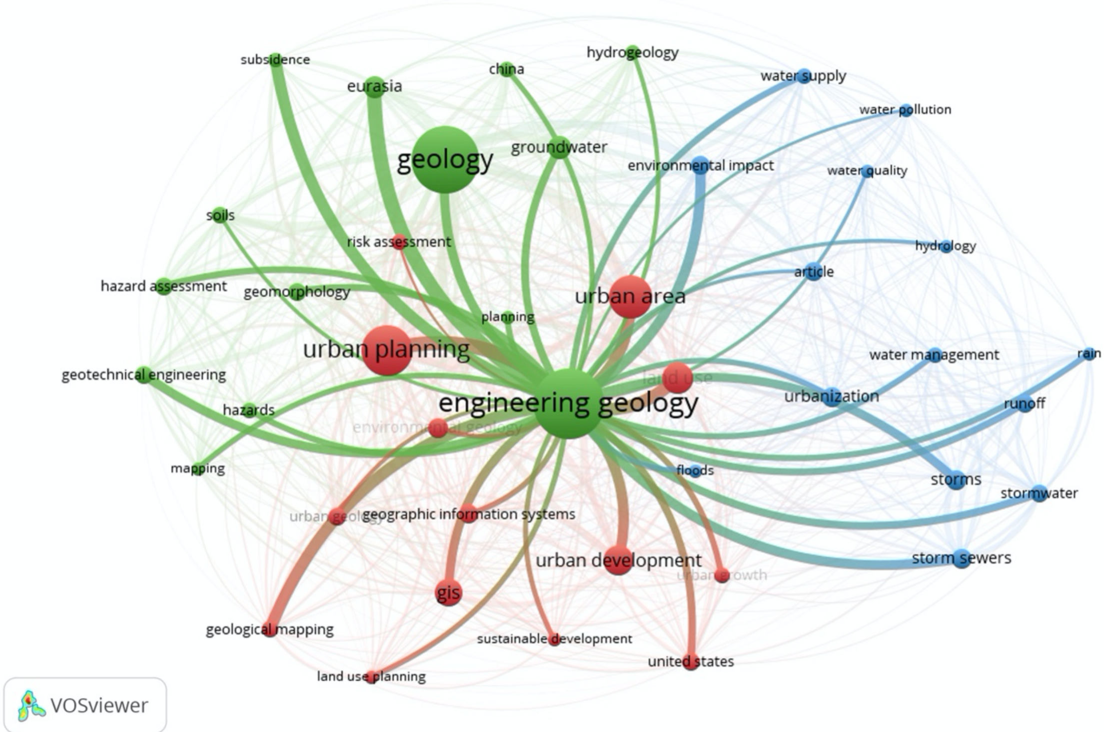

Figure 3. Co-occurrence network of engineering geology as a keyword in VOSviewer

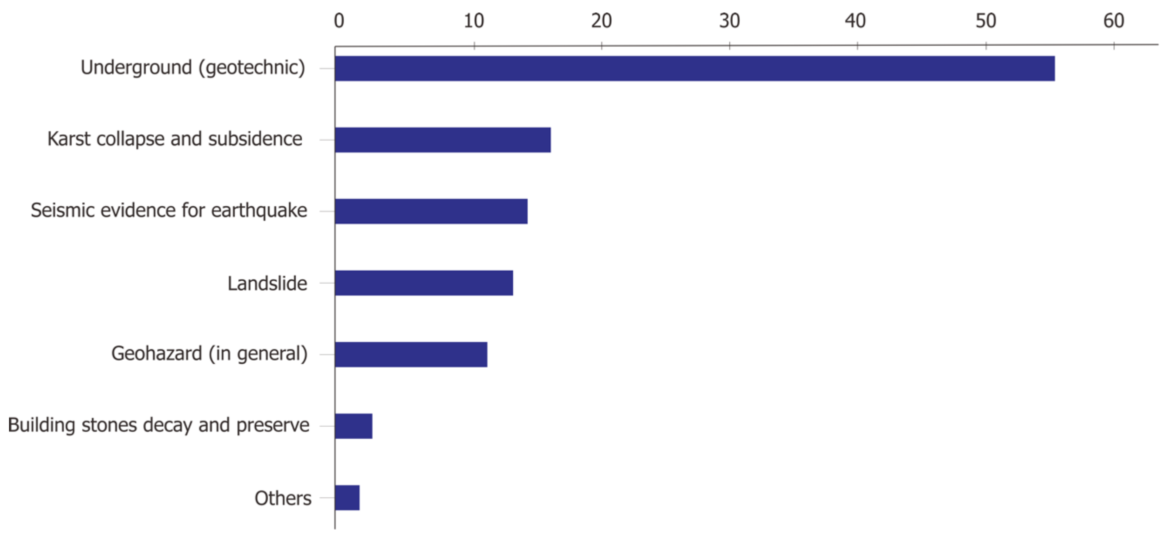

Figure 4. Key topics in the EGR cluster and number of articles published

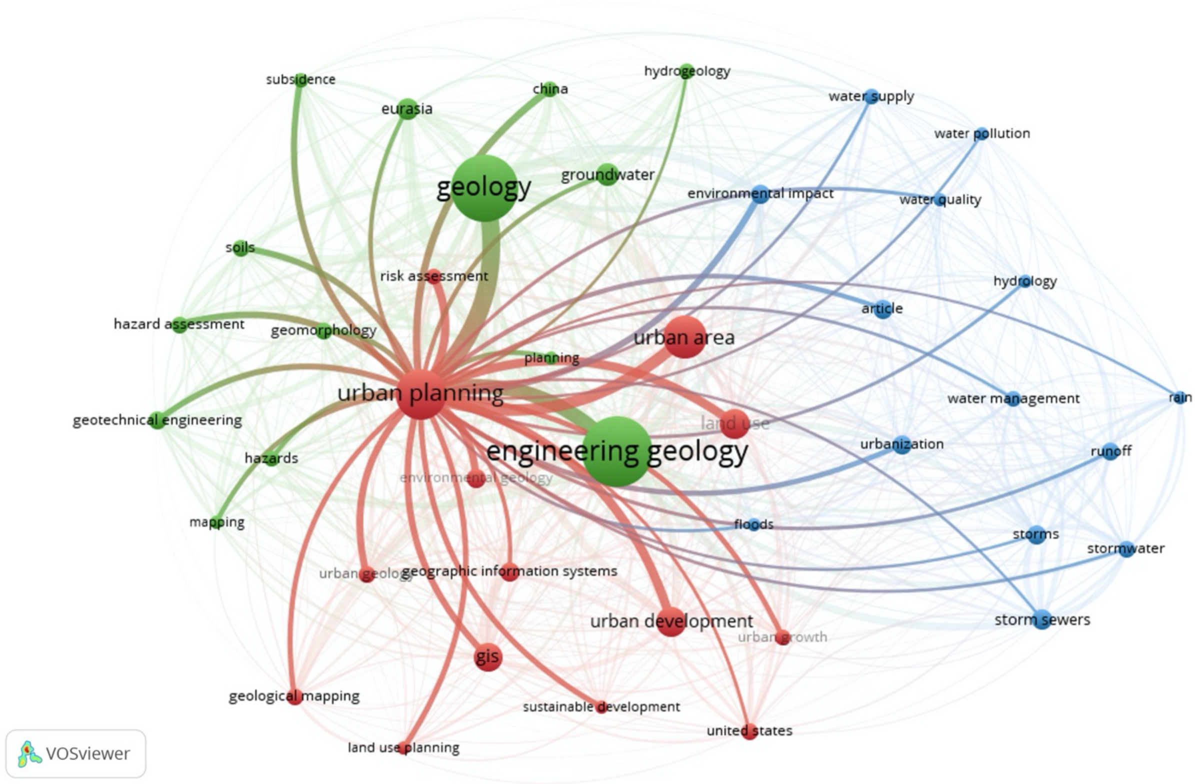

Figure 5. Co-occurrence network of keywords in cluster 2 (S.G.S.) using VOSviewer

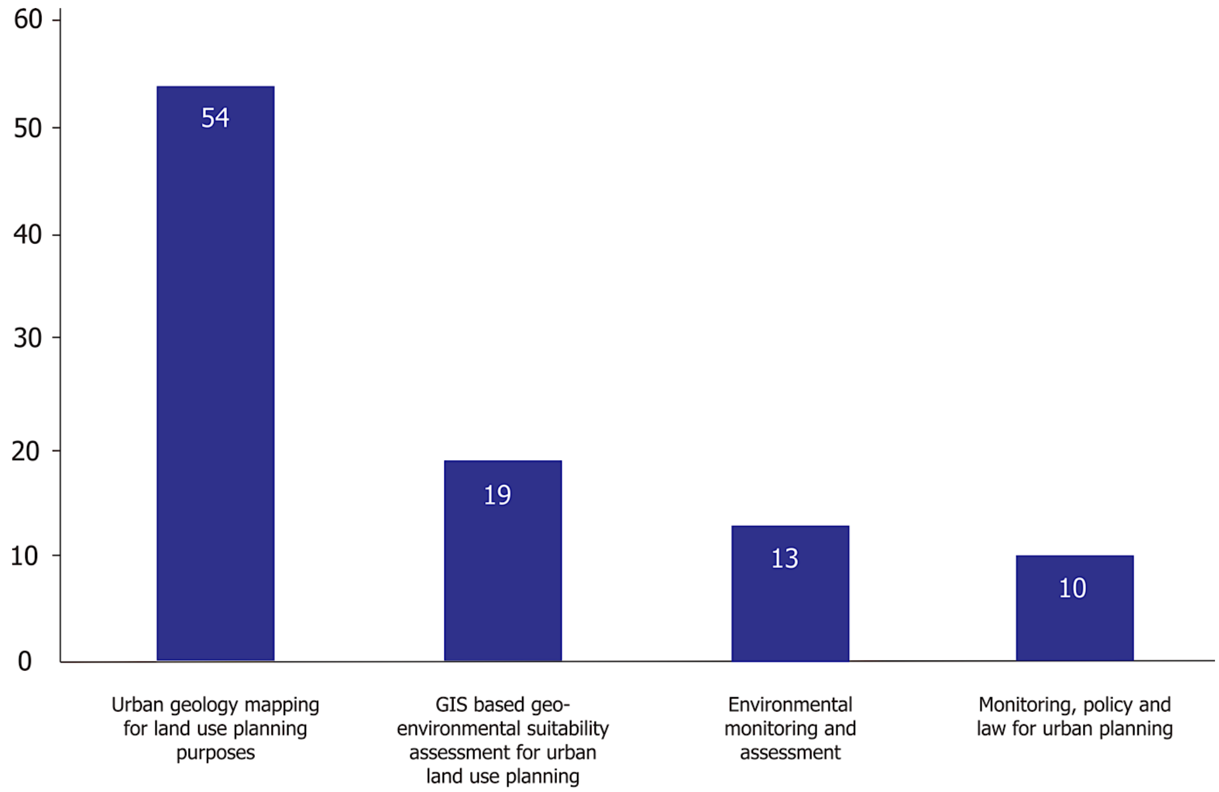

Figure 6. Key topics in the S.G.S. cluster and number of articles published

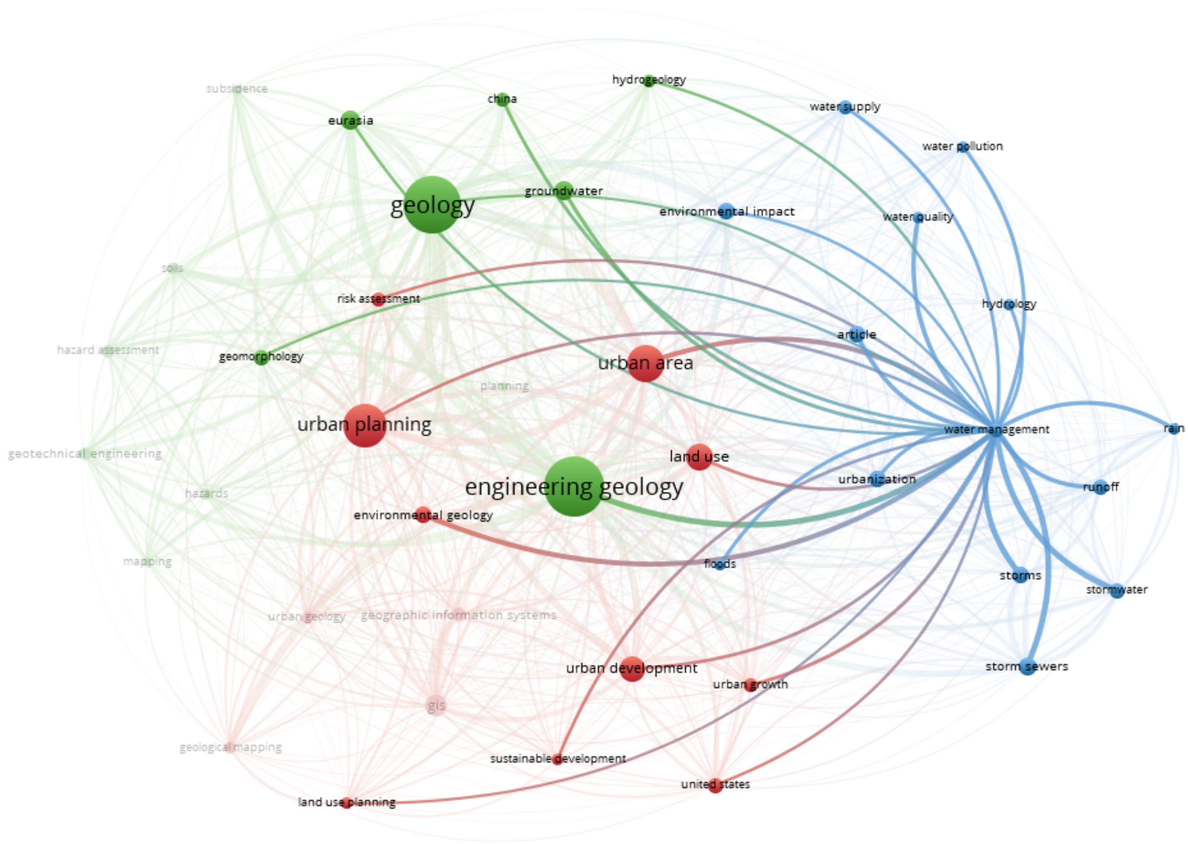

Figure 7. Co-occurrence network of water management as a keyword in cluster 3 (H.G.W.) using VOSviewer

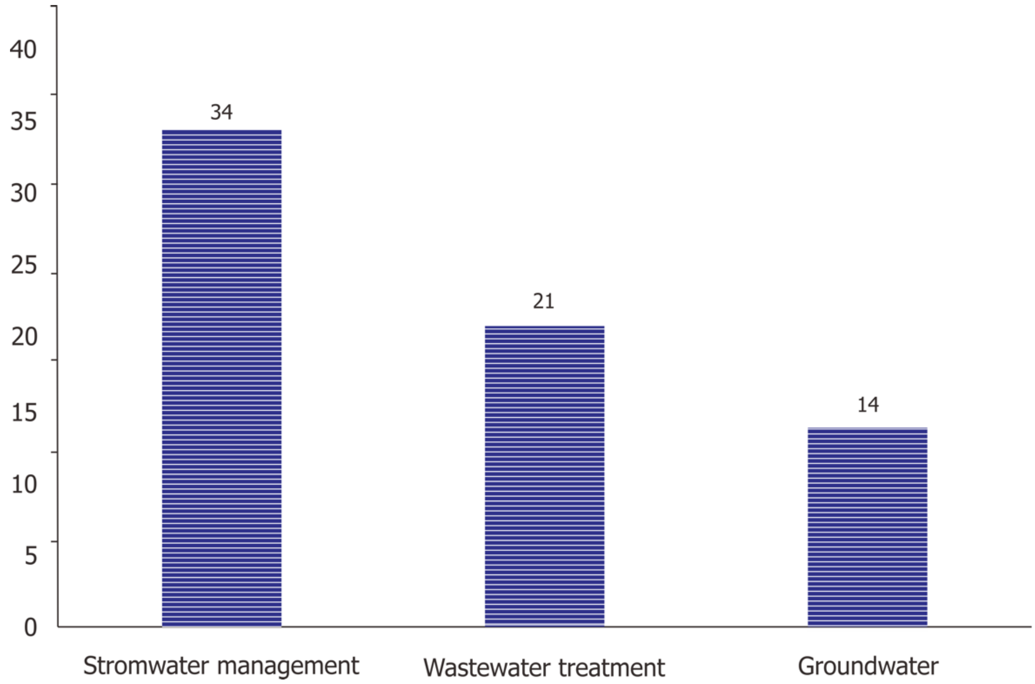

Figure 8. Key topics in the H.G.W. cluster and number of articles published