RESEARCH ARTICLE

Discovering research trends of urban geology based on a bibliometric analysis [version 1; peer review: 2 approved with reservations]

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Abstract

Urbanization contributes to the emerging urban areas across the world. The importance of geology to ensure sustainability, has led to many research publications in the 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 on topics related to geology and urban. The analysis found a significant increase in publications during 1999-2016, especially after the 2004 Indian Ocean earthquake and tsunami disaster. The next finding of this study is related to research interest clusters: 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). The EGR studies were mostly in underground engineering geology (geotechnics). In contrast, the least attention was given to the interaction between geology and land-use planning, due to the SGS issues (e.g., urban planning and land use suitability assessment). 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

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Introduction

The amount of research publications in the field of geology has reached a significant number. A broad search for articles that included geology as a keyword, was done with the use of the Scopus database, which resulted in at least 120,000 documents in more than 25 subject areas. By some, geology maybe viewed as identical to mining and petroleum, therefore, such topics indeed dominate about 45% of the total searched documents. Ore mining and petroleum industry commonly involved geological application in the less-populated areas. However, the rest of the searched documents ($\pm 55\%$) showed how geology is applied in the more-populated areas (urban area). This is now known as urban geology (UG), which is less popular among societies, despite it being beneficial for many people.

In 1950s after World War II, UG began to grow in the United States of America, particularly in California, because of land-use planning, as a result there was tremendous economic growth and urban expansion.¹⁻³ Intense meetings on UG were held in the 1960s till the 1970s,^{4,5} which was soon followed by the publication of a book called 'Cities and Geology'.⁶ As most of the world's population already live-in urbanized areas (>50%), in developing countries migration to these areas is on the rise.^{7,8} This can have significant challenges for urban areas since there is an increased pressure on resources, spaces, and services.^{8,9} For example, the zones that are available for construction are usually the least suitable, however the neglect of its geological setting potentially can lead to severe economic loss, e.g., tsunami destruction or building collapses. Therefore, geology plays a critical part in maintaining sustainable cities.⁶ At present, since urban areas have been the main attention of regional planning,¹ UG has become an essential part of engineering geology. However, the scope of UG is beyond just engineering geology as it connects with various aspects of life.¹⁰ Given its importance, UG is not fully appreciated by those in charge of the management and improvement of the world's cities. Perhaps it was 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 UG keeps growing, and various articles have been published on this topic. Unfortunately, the existing literature has a broad range which makes it difficult to derive the research trends on UG. Therefore, a better analysis of publications in academic journals would assist researchers and practitioners in exploring the current status and future direction in this area.¹¹ From 1970 till 2000s, organizations such as Association of Environmental and Engineering Geologists (AEG), Economic and Social Commission for Asia and the Pacific (ESCAP), and Geological Association of Canada (GAC), published a few books on UG.^{6,12-15} Limited articles presented in these books were short case histories on the urban or engineering geology of individual cities.¹ In contrast to these books, the present study has analyzed most of the research literature on UG. This study aims to investigate the research trends of UG based on bibliometric analysis. Therefore, the objectives were to assess the annual publication trend of UG-related research from 1950 to 2018. Additionally, this study aims to analyze the research topics of interest in UG from 1950 to 2018, and explain how these topics interact with each other, and investigate the gap in the current research trend.

The term bibliometric refers to applying a quantitative method to evaluate research within the applied science-related fields.^{11,16} Bibliometric analysis has become an essential and a frequently used method to detect areas that require further research to strengthen research capacity in the future, without bias.^{11,17} Bibliometric analysis has been utilised for big data research,¹⁸ public-private partnership,¹⁹ and stem research.²⁰ This study, however, was among the first to apply bibliometric analysis in the context of UG research.

Methods

Keyword approaches and framework

The sequence of numerous UG definitions between 1950 till 2018 in various literature is presented in [Table 1](#). Some UG definitions might be similar however they have different terminologies. This fact has led to a group formulation of preferred key concepts for UG that correlate with each other

From the definitions in [Table 1](#), it was clear that the terms UG, environmental geology, and engineering geology are interchangeably used.^{2,21,22} While the term urban was interrelated with the concept of "the city".²³ The city collectively is defined as a concentration of buildings, roads, public and private spaces, people, conflicts, and common efforts that is administratively delimited.^{21,22} An urban area has always performed with a wide range of city functions.²³ It is a settlement with a high population (where most of the population are not primarily engaged in agriculture, or where there is surplus employment), expanded beyond the administrative boundaries, and includes cities, towns even suburbs.^{23,24}

Moreover, the term city is frequently used to describe a metropolitan area, region, and urban agglomeration.²⁵ The Metropolitan area comprises of 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 is called a megacity.²⁷ These definitions suggest that the terms city (cities), urban, metropolitan (area), and megacity are interchangeable, depending on the context used.

Table 1. Various definitions of urban geology in sequence years.

Year	Definitions	Preferred key concepts
1970	"Urban geology in the modern context is considered to be a close synonym for environmental geology" ²¹	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" ²⁸	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" ²²	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" ³⁰	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" ³¹	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 geochemistry and hydrogeology to geophysical exploration techniques, linking to the biological and environmental sciences" ¹⁰	urban geology; urban areas; engineering geology; environmental science

Notes: In this table each definition is accompanied by selected preferred key concepts. The combination of these key concepts became keywords to filter literature in the Scopus database.

The preferred key concepts (Table 1) also shows how the UG definition was often approached by the concept of urban planning and development.^{4,25–27,30} Urban planning is the organized planning of the physical environment, where individuals live to create a healthy, reliable, and durable living space by providing safety in line with their social, cultural, and economic needs.³² Earth science factors (e.g., geology) are essential in planning for urban development initiatives. These factors address ground-related problems and other potential constraints on development.³³ The use of geology for

urban planning and development has been applied to earthquake hazard vulnerability,³² landslide susceptibility and risk zoning,^{33–35} seismicity,^{36,37} geotechnical issues such as erosion and expansive soil,³⁸ and flood hazard.³⁹ To emphasise the importance of this matter in 2014 the International Association for Engineering Geology and the Environment (IAEG) XII Congress in Torino, published a series of books as part of its proceedings on environment, processes, issues and approaches, with volume 5 titled “UG, Sustainable Planning and Landscape Exploitation”.³¹ At present, the need for geology in planning and development in the urban areas are expected to increase due to the rapid population growth.

Multi-stage data processing

The journal articles related to UG from 1950 till 2018 were searched in the Scopus database on July 24, 2018. Scopus was selected because it has the largest single abstract and indexing database.⁴⁰ Additionally, Scopus is the leading citation source to journal articles, compared to other bibliometric data collection tools.⁴¹

The selection method comprises of three stages. In the first stage, keywords were combined with the use of Boolean operators such as “AND”, “OR”, and “NOT”, in the Scopus search engine. The selection of keywords was taken from the key concepts, that had appeared in various definitions of UG, as explained in the previous section. The first search was “urban geology”, which resulted in 167 documents. The use of quotation marks (“ ”) was to search for the exact phrase as it appears in the articles. The second search was *environmental AND geology**, which resulted in 14,087 documents. The * symbol was used to search for an alternate word ending, while AND was used to combine the searched phrases without it becoming an exact phrase. It meant that the search results may have been from documents containing the word ‘environmental’, ‘geology’ or both words. The third search was *engineering AND geology**, which resulted in 25,303 documents. The fourth search was a combination of *geology* AND urban OR city OR cities OR metro* OR megacity* AND planning OR development*, that resulted in 4,798 documents. Some key concepts were truncated here as well with the use of the * symbol to obtain various search results (e.g., megacities, megacity for megacity*). OR was used to combine related terms or synonym for urban (i.e., city, cities, metropolitan, megacity). All four searches were thus stored in the search history. Finally, in this stage all four searches were combined as #1 OR #2 OR #3 AND #4. Sets of searches were combined using “OR” and “AND”. This combined stage resulted in 1478 documents. However, these results may include some irrelevant publications that had the searched keywords, that did not relate to UG.

The second stage involved the exclusion of document types, languages, and subject areas that were not directly related to UG. First, the search for the article type was limited, which resulted in 735 documents. Articles were then filtered for English language, reducing the resulted to 595 articles. The search was further narrowed down with the execution of 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 produced 529 documents.

The third stage involved exclusion of topics that are too broad based on title, abstract, author keywords, and index keywords. Results from the previous step, including information on citation and abstract, author, and index keywords, were included when downloaded as PDF. Hence, to ensure the relevant content, 529 abstracts in the PDF format were scanned to determine further exclusion from the results. At the end, 285 articles were selected (See [underlying data](#)⁴²). The summary of the three stages, and their refined results are shown in [Table 2](#).

Data analysis

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

However, for the observation of the research trends, the authors used the clustering technique provided by the open licence software tool, [VOSviewer](#) version 1.6.16.⁴³ VOSviewer clustering was done based on the fractional-counting method on the keywords in relations to the clusters. Visualization was presented in each set by color (i.e., red, blue, or green), which indicated the group in which the cluster was mapped.⁴⁴ The clusters were further analyzed to answer the research questions.

Results and discussion

Annual publication trend of urban geology-related research

The yearly distribution of the UG articles by publication is presented in [Figure 1](#). The search timeline was set from 1950 (the year when the UG topic began to grow) until 2018, however, the years in which publications were found ranged from 1970 to 2018. [Figure 1](#) shows a plateau in the number of publications between 1970 till 1981, with a slow increase in the number of publications from 1982 to 1997. A significant increase was observed during 1999–2016, as the number of

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

Stage	Inclusion/exclusion	Description	Search terms	Results
First	Inclusion based on searched 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 (geology* AND urban OR city OR cities OR metro* OR megacity* AND planning OR development))	1478
Second	Exclusion on document type	Only articles are included	AND (LIMIT-TO (DOCTYPE, article "ar"))	735
	Exclusion on language	Articles written in English are included. Those 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 based 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") OREXCLUDE (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

Notes: The *asterisk* symbol (*) is a wildcard symbol for finding words after the term "geology".

research articles increased from 9 to 17. From the 285 articles, one was published in 1998, and 187 articles were published in the 2000s. This could be explained by the fact that global research (including research in UG's field) declined due to the Asian financial crisis that happened in 1997-1998.⁴⁵ However, the UG concept emerged in the 2000s, especially after the 2004 Indian Ocean earthquake and tsunami disaster, to address urban resilience against natural disasters.

Research topic interests in urban geology

Research questions such as, "What was the UG research topic from 1950 to 2018?" and "How did these research topic interests interact with each other?", were answered with the use of the bibliographic data to construct a co-occurrence map in the VOSviewer software.⁴³ Several examples of similar analyses have been done in the field of general science and technology,⁴⁶ in geoparks,⁴⁷ in soil erosion,⁴⁸ and volcanic geomorphology.⁴⁹

For the data selection and thresholds, all keywords were divided into clusters with the minimum number of occurrences set at 15 keywords. Among the 2688 keywords, 42 met the threshold, which were presented as 42 nodes. Eck and

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

Waltman suggested that in constructing the bibliographic coupling networks, “fractional counting” instead of the ordinary “full counting” methodology, can result in all publications to have the same counting portion.⁵⁰

The processed bibliographic data resulted in the keywords that were grouped into three clusters as presented by the VOSviewer in Figure 2. The three clusters were represented by three different colors, in which green represents cluster 1, red cluster 2, and blue cluster 3. The nodes in Figure 2 represent a term, and the node's distance reflects the

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

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

relationship. Close distance between the nodes, reflect an intense relationship and a strong link between the two terms. Larger nodes represent a higher number of occurrences (high weighted). A summary of the clusters and terms are shown in [Table 3](#).

Each term was connected to other terms by a link representing the relationship between the two terms. The stronger the link, the thicker the display line.⁵¹ All terms are quantified according to their occurrences and link strength, as shown in [Table 4](#). The link strength indicates the strength of the relationship between the two terms and the total links between the nodes represents the sum of link strength of one node over others.⁵² As seen in [Figure 2](#), there are several significant nodes on the map which indicate the most common terms. They are “Engineering geology”, “Geology”, “Urban planning”, and “Urban area”. These four terms were covered in cluster one and two.

The following sub-sectional outline in the three clusters represent the three research topics of interest, such as 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 research on EGR (42%), followed by SGS (33,7%) and HGW (24,3%) topics.

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 showed thick lines connecting with most terms in all clusters, explaining the fact as to why UG research was mostly related to engineering geology. Other prominent terms in this area include “Geotechnical engineering”, “Subsidence”, “Eurasia”, and “Hazard assessment” ([Figure 3](#)).

There were 120 articles in this cluster. The articles were 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 were focused on underground civil planning (geotechnics) cases in urban areas (56 articles). The most popular topic was tunnelling,^{53–56} underground spaces,^{57–59} and geotechnical modelling.^{60–63} Case studies for these topics were mostly done in 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 Netherlands, Singapore, etc.

The next most significant focus of the EGR articles studied were karst collapse and subsidence cases (22 articles), seismic evidence for earthquake cases (16 articles), landslide cases (14 articles), and other types of geohazards cases in general (12 articles). Research on karst collapse and subsidence were mostly done in European countries such as Italy, Spain, and Belgium.^{63–65} While for landslide, the related topics are land-use and landslide,^{66,67} landslide vulnerability and risk assessment.^{68–70} Other issues related to seismic evidence for earthquakes are mostly on earthquake hazard cases, situated in Turkey’s urban area.^{71–74} Eurasian Plate movement was the most frequently discussed topic in these earthquake hazard cases. In addition, some researchers analyzed the engineering-geological hazard investigation and risk assessment for all possible aspects in the urban area. We found that there were papers that discussed the role of engineering geology for building conservation.^{75–77}

The oldest publication listed in this cluster was an Indonesian study from 1970, which was on the application of engineering geology for the regional development and UG.⁷⁸ Previously, the main role of engineering geologists in

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

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

Indonesia was to give advice to large civil engineering construction projects, in addition to increase the importance of human resources.⁷⁹ This might suggest that the initial idea of engineering geology as part of UG in Indonesia was not fully researched. However, there were a small number of articles in this cluster that were related to volcanic eruptions,⁸⁰ flood,⁸¹ and building stone decay and preservation⁸² (Figure 4).

Cluster 2: Social geology and urban sustainability (SGS)

Cluster 2 was represented by 14 red colored nodes in which the five highest weight and total link strength keywords were “Urban planning”, “Urban area”, “Land use”, “Urban development”, and “GIS” (Figure 5). However, the close nodes between “Environmental geology” and “Urban planning”, and the very thick line between “Geology” and “Urban planning”, can be used to explain how urban planning and geology were interrelated and what they shared, in the domain of environmental geology.

There were 96 articles in this cluster with 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.⁸³ SGS included geo-environmental appraisal in the developing urban areas. It ranged from UG mapping for land-use planning (54 articles),

Topic	Percentage (%)
Underground (geotechnic)	55
Karst collapse and subsidence	16
Seismic evidence for earthquake	14
Landslide	13
Geohazard (in general)	11
Building stones decay and preserve	3
Others	2

The topic that received the most attention in this SGS cluster was related to UG mapping for land-use planning purposes.^{84–88} The 54 articles on this topic were mainly published before the 2000s, with a slight decline after this period. This was before GIS (Geographic Information System) studies were well-developed and applied. Since the early 2000s, mapping for urban land-use planning has taken a GIS approach, instead of relying on field geological investigation. GIS-based geo-environmental suitability assessment for urban land-use planning has been the second major topic in this cluster.^{89–92} Most of GIS approach in the study collaborated with AHP (Analytic Hierarchy Process) method.^{93,94} Similarly, Ulfa, et al. presented the results of their study with the use of APH in geological research for urban land-use in Indonesia.⁹⁵ The third topic in this cluster was related to the environmental monitoring and assessment^{96–98} and monitoring, policy, and law for urban planning^{99–101} (Figure 6).

Urban Planning Application	Percentage of Respondents
Urban geology mapping for land use planning purposes	54
GIS based geo-environmental suitability assessment for urban land use planning	19
Environmental monitoring and assessment	13
Monitoring, policy and law for urban planning	10

Cluster 3: Urban hydrology and water management (HGW)

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

“Stormwater”, and “Flood”. Stormwater was defined as rainwater that is runoff from land or built-up on surfaces such as roofs, driveways, pavements, footpaths, and road infrastructures, without entering the drainage system.¹⁰² The existing issues regarding stormwater are pollution and flood.^{103,104} One of the best management practices to control stormwater pollution is developing a sewer system called storm sewer, expected to be different from wastewater sewer.¹⁰⁵ Moreover, storm sewers can be a solution for reducing floods by minimizing the discharge rate from the urban catchment areas.¹⁰⁶ However, this is more relevant to the urban water (hydrology) management, which is a domain of civil or environmental engineering instead of geology.

There were 69 articles in this cluster (Figure 8), of which 34 articles were focused on stormwater management (including flood assessment and modelling, urban stormwater, and storm sewer). The second focus in the cluster was on articles regarding wastewater treatment, including water quality and geochemistry (21 articles). The third focus was on 14 articles concerning groundwater, which was the only cluster that matched with geology as a scientific topic.⁹⁹⁻¹⁰² While the first and the second focus emphasized more on water engineering or applied technology aspects.

Research gaps and future studies

In the past 40 years the increasing trend of UG research was in line with urbanization, even though there was a slow trend before the 2000s. Events such as the Indian Ocean earthquake and tsunami in 2004 that led to the killing of thousands of people who lived in urban areas, were triggers that increased the research in UG in the years to come. In 2015 the initiation of Sustainable Development Goal (SDGs) engaged geologists to have a role in helping and ensuring sustainable foundations for future global development.¹¹¹ Among the agreed geological aspects in SDGs that were in line with this study are engineering geology, geohazard, hydrogeology, and geo-heritage.¹¹¹ Since then, many UG articles were trying to relate their studies to the sustainable development concept.^{76,112,113} Therefore, the research and application of UG has been postulated as a promising approach for sustainable development goals, especially for the 11th goal (sustainable cities and communities), since 55% of the world’s population in 2018 was estimated to live in urban areas.¹¹⁴ It is expected that UG research will have increased popularity among researchers in the future.

The results of this study found that there were more research articles on EGR than on SGS and HGW topics. Most of the current research mainly focused on engineering geology related to hazard investigation and risk assessment for underground geotechnical construction. The main focus of underground geotechnical research was on case studies in

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

developed countries, specifically in the Metropolitan areas, such as New York, San Francisco, Tokyo, Toronto, London, Singapore, etc. It is because the demand for underground infrastructure as solutions for traffic is growing in Metropolitan cities. Recently, those related to natural hazards such as subsidence, landslide, and earthquake in urban areas have also received attention, however they were viewed from an engineering geology perspective. In the future, it would be interesting to explore and examine the influence and challenges of UG in developing countries.

As shown in Table 4, the term “land use planning” has the lowest link strength within the whole three clusters. Among other terms which have lower link strength was the planning and sustainable development. These results indicate the most significant gap in UG studies was the interaction between geology and the land-use planning studies, which are under the umbrella of SGS. It was also indicated that sustainable cities and the communities have not yet considered geology for measuring a successful goal. Approach methods using GIS and AHP or even SMCE (Spatial Multi-Criteria Evaluation) can be explored in the future studies of geology for urban land-use planning and development.

Discussions on flood hazard and urban hydrogeology in this article were minimal. Urban water-related articles which are covered in UG topics were mostly discussed in terms of quantitative water management, storm sewer, and stormwater pollution, which does not fit in the scope of geology, even though it is covered in civil engineering. Articles within the scope, published prior to 2000s, were still lacking quantitative analyses. However, they are in need of necessary geological information on the water condition (either groundwater or surface water) presently, in order to answer practical hydrogeologic management and engineering questions. As expected hydrogeologic science is not well suited for quantitative prediction, however, it is best suited for providing theoretical and basic scientific solutions for complex practical problems.¹¹⁵

Conclusions

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

The term UG has increasingly evolved over the past few decades. UG was first mentioned in an article that was published in 1970,⁷⁸ as part of the engineering geological assessment for urban planning and development. UG has been further applied beyond the engineering geology and civil engineering. It is emerging as the application of the Earth sciences for any problems arising within the urban areas. UG 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 urban geology (UG) related articles 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 further categorized into sub-topics. These were underground geotechnics; karst collapse and subsidence; landslide; earthquake; building stones conservation; general engineering geological hazard cases; UG mapping for land-use planning; GIS-based geo-environmental suitability assessment for urban land-use planning; environmental monitoring, assessment, and landscape management; monitoring, policy and law for urban planning; stormwater management; wastewater treatment; and groundwater. The summary of these research interests has provided an overview of the development of UG in the academic field as a platform for scholars to continue the trend, or to explore a new direction in this topic.

The limitation in this study was the sample size. Ideally, bibliometric analysis should have consisted of data sets collected from Scopus, Web of Science, and Google Scholar, in order to increase the sample size (number of articles),¹¹⁶ and to create a more comprehensive research. Other limitation is that the articles published in the last 3 years were not included, since the manuscript was firstly drafted in mid-2019.

Author contributions

Irawan, DE: Conceptualization, Writing – Original Draft Preparation, Writing – Review & Editing; **Ulfa, Y:** Conceptualization, Writing – Original Draft Preparation, Data Acquisition, Writing – Review & Editing; **Prabowo, RM:** Data Acquisition, Image Curation; **Kombaitan, B:** Writing – Review & Editing; **Puradimaja, DJ:** Writing – Review & Editing

Data Availability statement

Underlying data

Figshare: Discovering research trends of urban geology based on a bibliometric analysis

DOI: <https://doi.org/10.6084/m9.figshare.14864895.v7>.⁴²

The project contains the following underlying data:

- Scopus_285_urbangeology.csv (raw dataset containing corpus downloaded from Scopus)

Data are available under the terms of [the Creative Commons Attribution 4.0 International license \(CC-BY 4.0\)](#).

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Károly Németh

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This is an interesting and eye-opening manuscript that could be developed to be a good research publication. As I answered "partly" to each of the Journal Review Report questions, it reflects my feeling that the manuscript left many questions open or not fully developed to provide a reasonable answers. I have this impression in every part of the manuscript.

Here I provide a short summary to support my report:

1. The manuscript is well designed and offers an easy to follow structure with clear references to figures and other external data/information. While this is very promising, nearly every section contains paragraphs that contain isolated statements without deeper explorations of the reason behind those findings. I was expecting that in the discussion I would read a more in depth analysis of the results (e.g. as a comparative study), but the text offered very little in that direction.
2. The Abstract is okay, but somehow it lacks a real punchline. The key essence of the research outcome should have been the main part of the abstract instead of the too general statements as the Abstract is currently designed.
3. The Introduction provides a good summary, but completely lack of some sort of "aim - objective" section where the reader directly pointed to the Authors null hypothesis, the aim to conduct such research and what potential benefit we can have if we do something like this. I think this is probably one of the major flaw of the manuscript. While I am involved in similar research the manuscript provided limited reason why I should read this work. These days similar literature reviews are common and the reader really needs to know why a work like this important.
4. Following the previous point, similar works commonly referred to as "systematic literature review" or "systematic mapping of xyz" and such researches has an extensive literature mostly within social sciences. Some citation to those key works would have been good here. Check those few listed after the report.

5. From a methodological point of view, more detail is needed to justify why Scopus is the best for this research. In a very short section this is mentioned but not fully elaborated. Technically, Scopus indeed the most practical database to handle, but obviously the results will be limited. Some sort of evaluation, at least a very simple one about what to expect if we have Web of Science, Science Direct, Google Scholar or JSTOR for instance in the analysis. I think such critical expression over the expected trends would be a very good addition to the work.
6. Somehow it is "overrated" that over time an explosion of publications within geology can be seen. This is however not only true for geology but any other subjects and controlled by a multitude of factors. It would have been really great to read some lines how this global trend filtered out.
7. The data presenting section is fine but always stops before actually some interesting conclusion reached.
8. Same as the point above, the discussion has a lot of room to develop. For the results, it would be good to have a contrast in a regional base, or country, if possible. While as a reader, the manuscript helped me develop some sort of conclusion on how to interpret the results presented here, to elevate the scientific value of the manuscript, the authors need to offer this. For instance, the research results indicate some urgent policy developments through some fields, or the results reflects some sort of limited directions everyone focuses but for manage urban sustainability other research directions need to be identified, ... then how ...? A little bit of philosophical critical evaluation of the research result would be a very interesting part of the manuscript.

Overall I think this manuscript can be a valuable work if the authors find the focus and big picture aim to present their results.

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Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

Partly

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Partly

Are all the source data underlying the results available to ensure full reproducibility?

Partly

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: geology, sedimentology, volcanology, geoheritage, geodiversity, geoconservation

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Reviewer Report 11 October 2021

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This manuscript performs a bibliometric analysis with focus on “urban geology” (UG). The analysis identifies 3 main clusters within the literature pointing to risk, water and society. The analysis appears sound and is overall well-presented and summarises past, current and future trends in research quite well. However, there is considerable room for improving the manuscript, particularly in formulating clearer aims and requires careful editing to ensure the outcomes are clear.

The abstract is okay, needs a bit of editing to make it clearer, and importantly to sell the findings. Why, for example, is the discovery of the 3 clusters important and useful for UG? You state it might inform researchers of where the research is at and inform future research. Perhaps you can provide supportive examples that show the way forward. To give a fictitious example, “very few

articles address links between geology and human health in built up areas”.

In my opinion, the article seems to adopt an 'analyse and see approach' as opposed to starting with testable questions. This is in principle okay, but you still need to clearly explain early on why you are doing this study. For example, why is doing this exercise important for the study of Urban Geology? For example, after reading and introduction, I did not really understand why this research is important or in fact why “urban geology” is important. It would be great if you can start by defining the science and why it is important. Perhaps provide a bit of history and context of UG. For example, I recommend starting the introduction with “Urban geology is the science behind understanding and managing the subsurface in urban areas. This includes, research areas such as hydrogeology, geoheritage, geoengineers,...”. You could move the second introductory paragraph to the first, the first paragraph may be better in the abstract as it is results. Furthermore, in my opinion, bibliometrics hardly needs a mention in the introduction as this is the method you will use to get a better understanding of the directions UG is taking and whether there are clear gaps in the research. Where you do mention bibliometric analysis, you might consider providing evidence as to other research areas have benefitted from this type of analysis to convince that it is the right analysis for the job.

The methods are okay, bibliometric analysis is fairly well described. However, I was wondering why you have not considered a citation analysis as part of your analysis as this can elucidate some weight or influence in different research areas identified (quantity and quality)? Other metrics to include that indicate quality might be journal rankings in field or similar.

In my opinion there are quite a few statements with little or no support. For example, the following statement claims that UG will increase in popularity because 1) the SDGs and 2) increasing urban population. But it is not clear whether growth in 1) & 2) implies growth in UG (causality): *“Therefore, the research and application of UG has been postulated as a promising approach for sustainable development goals, especially for the 11th goal (sustainable cities and communities), since 55% of the world’s population in 2018 was estimated to live in urban areas. It is expected that UG research will have increased popularity among researchers in the future”*. - Evidence for causality would be, for example, that many of the recent publications in UG mention the specific SDG.

Similarly, it is stated that *“It was also indicated that sustainable cities and the communities have not yet considered geology for measuring a successful goal.”* This needs more explanation. How might a city consider geology in measuring success? This and the previous example are just a few examples of where the article would benefit from articulating what the key findings are of the bibliometric analysis and why they are important.

A final example is, *“There were 69 articles in this cluster (Figure 8), of which 34 articles were focused on stormwater management (including flood assessment and modelling, urban stormwater, and storm sewer). The second focus in the cluster was on articles regarding wastewater treatment, including water quality and geochemistry (21 articles). The third focus was on 14 articles concerning groundwater, which was the only cluster that matched with geology as a scientific topic.99-102 While the first and the second focus emphasized more on water engineering or applied technology aspects”*. - Given this is part of the discussion, would it not be a good space to relate this back to why this is relevant to UG. Currently this reads exclusively as results and so the importance in the context of the paper is lost.

In addition to the above, the manuscript also uses examples specific to Indonesia, I am wondering whether this may be more useful as a case study to show how UG is developing in Indonesia (trends). However, this will very much regionalise the paper so it should be part of a broader comparison or together with case studies in other regions i.e. you mention New York and other cities.

Maybe it was buried within the article, but the world health was only mentioned once – understanding linkage between UG and health within a “one health” framework or similar would appear to be a big gap in the current research.

In summary, while I think the analysis is a good start and there are some potentially interesting findings, these are still very much presented as statements of the results. While there are glimpses of potential, I believe that the paper needs to better discuss the findings in the context of historic development of UG and show the way forward in UG. Essentially, you have some evidence that it is a growing science, but you want to convince that it is a critical field of research to ensure the sustainability of modern cities now and into the future.

Is the work clearly and accurately presented and does it cite the current literature?

Partly

Is the study design appropriate and is the work technically sound?

Yes

Are sufficient details of methods and analysis provided to allow replication by others?

Partly

If applicable, is the statistical analysis and its interpretation appropriate?

Yes

Are all the source data underlying the results available to ensure full reproducibility?

Yes

Are the conclusions drawn adequately supported by the results?

Partly

Competing Interests: No competing interests were disclosed.

Reviewer Expertise: Hydrology, environmental science, data science

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however I have significant reservations, as outlined above.

Author Response 13 Oct 2021

Yuniarti Ulfa

Dear reviewer,
Thank you for the detailed review and some insights given. We will do revisions as suggested.

Competing Interests: No competing interests were disclosed.

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