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REVIEW ARTICLE

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Urban planning and development in harmony with the geosciences

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Abstract

Urban geology is the study of the different geological elements that impact and restrict human activities in engineering and economics inside urban areas. Over half of the world's population, or 4.2 billion people, lived in urban areas in 2018. Projections suggest that by 2030, this figure will rise to nearly 5 billion. Notably, the majority of this urban growth is anticipated to occur in developing countries, with towns and cities in these regions accommodating around 80% of the urban population by 2030, as stated by the United Nations Population Fund in 2007. A quick and comprehensive review of the literature reveals the growing importance of urban geology as an emerging area of study as well as the vitality of geosciences for natural disaster mitigation, resource management, sustainability, and understanding geological processes and natural hazards. Interdisciplinary research and collaboration between geologists, engineers, architects, urban planners, and policymakers at the national and local levels is inevitable given the current acceleration of urbanization and rapid environmental degradation as a backdrop. Geology is also an essential part of site selection, infrastructure design, and construction, water resources management, land use planning, and environmental protection during the urban planning and development phases. Incorporating geoscience insights into planning processes and raising public awareness allows cities to be planned and managed in ways that promote sustainable development, and resilience to natural disasters, and safeguard residents' health and well-being. In order to construct safer, more resilient, and sustainable cities for our communities and future generations, geoscience education and research must be acknowledged within the scientific research agendas related to urban planning, development, and transformation endeavors. Given the above, this study aims to examine the close relationship of geosciences with urban planning and development activities and to investigate and analyze the impact of geological factors on the urbanization process. This research also aims to raise public awareness about the importance of geology among the people who live in urban areas.

Keywords: Urban Planning; Urban Geology; Urban Development; Urban Transformation

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1. Introduction

Urbanization and the special challenges it presents to geologists led to a steady evolution of the idea of urban geology, which deals with understanding geological processes, geohazards, and resources within urban environments [1]. Urban geology is not the same as environmental geology; rather, it is the study of land resources and geologic hazards as they relate to the growth, rehabilitation, and expansion of urban areas [3]. Urban geology is the study of the different geological elements that impact and restrict human activities in engineering and economics inside urban areas [2]. Urban geology holds significant importance within the field of environmental geology, serving as a crucial component in human engineering and construction endeavors [3]. Its primary focus is on urban construction planning, making it a practical geological discipline. Although geology has always had an impact on cities, the phrase "urban geology" and the field's focused investigation only began to take shape in the middle of the 20th century, particularly in California. The U.S. Geological Survey (USGS) started mapping cities in the early 1900s after realizing the value of comprehending the geology of urban regions, even though the term had not yet been coined. The phrase "urban geology" was assigned to John C. McGill in a 1964 USGS publication [4]. Urban geology originated in North America in the late 1960s and early 1970s. The research and strategies to reduce the urban geological hazards in Asia have gained momentum after the integration of the field of geology with social and economic aspects in the 1990s. The role of urbanization and urban geology in this case have been brought to light and therefore numerous research in this field have been carried out. These studies are of significance as they bring the subject of urban planning and geology to the table. For instance, Zengin [5] conducted a research on the inundation effects of the Antalya Gulf, an over-developed tourist area located on the Mediterranean coasts of Türkiye. The findings of this study show that the sea level rise in the following 60 to 80 years is likely to lead to the loss of more than 250 square kilometers of land and the radical change of the coastline [5]. Another research [6] has proposed the Tomorrow's Cities Decision Support Environment (TCDSE), which is a method for advanced physics-based optimum determination of hazard and engineering modeling. This interdisciplinary approach is comprised of a combination of the physical and social effects and a flexible method for quantifying impacts which makes the concept of risk more understandable to the general public. Also, the study was meant to be flexible and could be applied to different scales of urban areas, involving steps of stakeholder engagement and technical tasks. This comprehensive study of the issue indicates that future urban planning may be done considering multi-hazard risks by means of a new approach for decision-making [6]. Furthermore, in Denmark, a 3D model of the geotechnical characteristics and geology of the urban regions was built in 2020 for urban planning and development efforts [7]. During this study, multiple-scale geophysical and geological maps were conducted in conjunction with the well data and geotechnical investigations to assess the functions of the geoscientific survey techniques utilized in mapping the geology, hydrology, and topsoil characteristics of the urban regions in Denmark [7]. After the devastating earthquakes in Türkiye in 2023, many municipalities swiftly implemented urban transformation plans to ensure buildings are resilient against earthquakes and began to embrace the importance of urban geology more significantly.

Over half of the world's population, or 4.2 billion people, lived in urban areas in 2018 (Figure 1). Projections suggest that by 2030, this figure will rise to nearly 5 billion. Notably, the majority of this urban growth is anticipated to occur in developing countries, with towns and cities in these regions accommodating around 80% of the urban population by 2030 [8]. Sustainable cities are one of the 17 Sustainable Development Goals of the United Nations set forth to be accomplished by 2030 [9]. The organization has identified major objectives for the upcoming ten years, including resistance to geohazards, sustainable development, responsible urban design, and preservation of natural heritage [10]. Unplanned urbanization, a significant consequence of population growth, is frequently intensified by the influx of people migrating from rural to urban regions [11]. Urban regions are commonly marked by high levels of industrial activity, often without proper regulation, as well as rapid and inadequately planned expansion. Additionally, natural habitats are frequently fragmented, and both surface and groundwater quality suffer from degradation caused by various chemical pollutants [12]. Urbanization concentrates human ingenuity, propels the world economy, and produces major social benefits. However, it is also an important factor in most environmental problems [12].

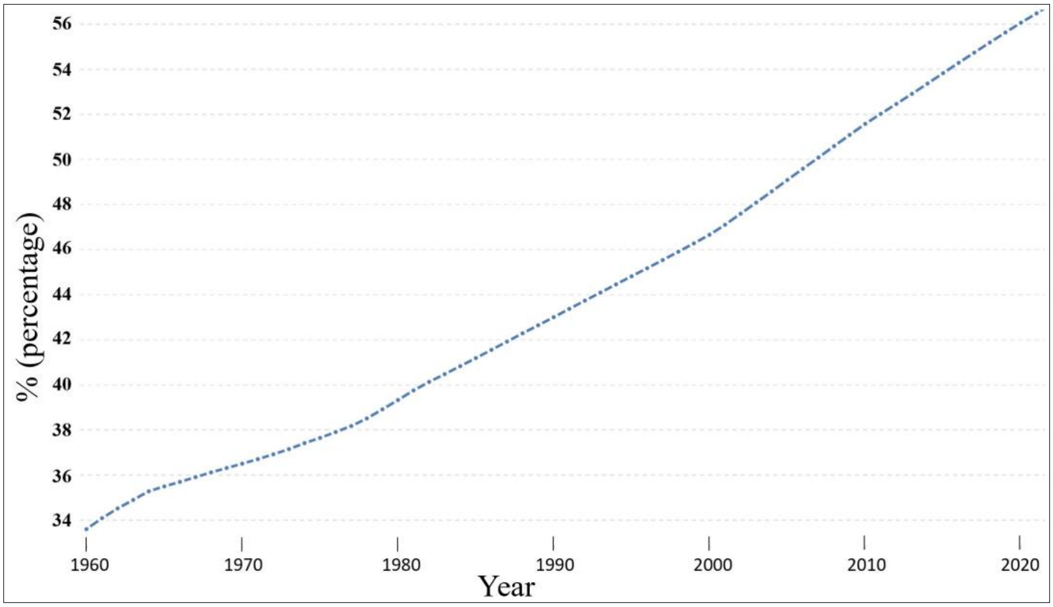

Fig.1. The chart illustrates the fluctuation in the percentage of global urban populations over the years [9].

Economic and social variables are typically the main emphasis of urban planning, development, and management processes [8]. Many people participating in the planning process have little interest in geoscience knowledge unless it is driven by a specific development project or hazard. A portion of this apathy stems from the fact that geoscience topics are rarely adequately covered in fundamental education; topics like minerals, water supply, and environmental hazards are usually saved until later grade levels. Convincing individuals to give geoscience issues top priority might therefore be difficult. With the exception of natural phenomena like earthquakes, volcanic eruptions, and tsunamis, the general public's perspective of geology is that it deals with events that happen on a timescale that seems remote and unrelated to present issues [13]. Rather, economic and social concerns including housing, work, health, and crime rates are more often given priority [13]. An overview of the main factors considered in urban geology, urbanization, and urban planning and development was given in Table 1, highlighting their interconnections and significance in sustainable city development. According to Marker [13], the significance of integrating foundational data into the creation of efficient planning regulations, sustainability analyses, and environmental impact assessments is recognized by geoscientists. In addition, this information offers crucial background for carrying out site assessments and determining the requirements for planning and environmental permits, which was provided by Marker [13] as follows: Quarry locations, mineral protection zones, water resource protection, agricultural preservation, ground condition assessment, conservation sites, hazard zones, pollution control, waste management zones. Furthermore, the main geological problems that need to be focused on before starting urban transformation or urbanization plans are provided in the European Union's Urbanization Plan as follows [14]:

- Landslides
- Earthquakes

- Sinkholes
- Land subsidence
- Groundwater pollution
- Volcanic activity
- Floods/Tsunamis
- Erosion and deposition
- Saline soils

To address these fundamental geological challenges in urban areas, it is essential to ensure the availability of the data outlined below. If this data is not already accessible, efforts should be made to obtain it promptly [14]:

- Geological maps.
- Groundwater depth/flow/quality maps.
- Maps that display catchment area locations.
- Maps illustrating the locations of rock quarries, pits, and mining activities.
- Locations maps for ground subsidence.
- Resource maps illustrating the distribution of possible landslides.
- Soil and water pollution and geochemical distribution maps.
- Maps for foundation characteristics and levels displaying the types and depths of foundation levels.
- Soil maps indicating the soils prone to erosion.
- Geologic map of Quaternary (alluvium, colluvium, terrace, etc.) units.
- Distribution map for urban and agricultural lands.
- Literature and publications

Table 1. The table presents a comprehensive outline of the key elements examined in urban geology, urbanization, and urban planning and development, emphasizing their interrelations and importance in fostering sustainable city growth.

Factors	**Urban Geology**	**Urbanization**	**Urban Planning and Development**
Geological Hazards	Identification of seismic zones, fault lines	Impact of geological hazards on urbanization	Incorporation of hazard mitigation plans
Subsurface Conditions	Soil types, groundwater levels, bedrock geology	Influence of subsurface geology on infrastructure	Consideration of subsurface conditions in construction
Land Use Patterns	Geological suitability for different land uses	Impact of urbanization on land use patterns	Zoning regulations based on geological factors
Natural Resources	Identification and management of mineral deposits	Urbanization's impact on resource depletion	Sustainable resource management in urban areas
Environmental Impact	Assessment of geogenic impact on ecosystems	Anthropogenic effect on environmental degradation	Implementation of measures to mitigate environmental impact
Infrastructure	Geological factors affecting infrastructure stability	Urbanization's demands on infrastructure	Planning and development of resilient infrastructure
Geological Mapping	Mapping of geological features and hazards	Incorporation of geological data in urban planning	Utilization of geological maps for city planning

Land Stability	Evaluation of slope stability, landslide susceptibility	Urbanization's impact on land stability	Implementation of measures to ensure land stability
Geological Surveys	Conducting surveys for land development projects	Addressing geological concerns in urban growth	Utilization of surveys for informed decision-making
Climate Change Impacts	Understanding geological responses to climate change	Impact of climate change on urban areas	Integration of climate change adaptation strategies

Sustainable urban growth, planning, and transformation strategies, as well as environmental preservation and comprehensive land use planning, depend on these steps. As cities continue to evolve, it is critical to understand the role that geology plays in urban development and planning. For example, the catastrophic effects of Türkiye's 2023 earthquakes on urban areas have once again underlined the importance of urban geology in the city and regional development, and transformation efforts in cities.

The main goal of this study is to examine the close relationship of geosciences with urban planning and development activities and to investigate and analyze the impact of geological factors on the urbanization process. This research also aims to raise public awareness about the importance of geology among the people who live in urban areas.

2. Collaborative approach

An interdisciplinary working group of engineers, architects, urban planners, geologists, and city authorities is needed to offer a solution-oriented approach to adopt all the kinds of challenges faced by local people during urban planning, development, and transformation activities [15]. With the rise in the population of cities in recent years which has made the socio-economic issues more complicated, it has become inevitable to set up the social-economic working group within the local governments. Interdisciplinary work is a cooperation that is done through holistic and integrative processes, which are based on the individual analysis of data by each discipline and the integration of the knowledge, as the creation or expansion of safe and sustainable urban areas [16]. In particular, geoscientists can share critical information with this working group by conducting comprehensive studies to identify and, if possible, prevent potential geological natural disasters in the environments where urban areas are planned to be established. On the other hand, architects and civil engineers play an important role in creating safer and more robust building stocks by adapting the critical data provided by geologists to their designs to ensure infrastructure stability and the safety of human life and property. Additionally, urban planners, in the light of the data they receive from geologists, make urban transformation or expansion plans in places where environmental factors will have the least impact. This interdisciplinary approach will not only minimize environmental destruction but also minimize the effects of any natural disasters that could potentially harm people. For all these reasons, it is very important for a sustainable and safe urban life that geoscientists conduct comprehensive studies before urban planning, development, and transformation activities and share this data with other disciplines.

3. Geological factors in site selection

In countries like Turkiye, Japan, New Zealand, and Indonesia, where tectonic movements occur frequently, it is a well-known fact that every devastating earthquake and natural disaster reminds people that geology is particularly critical for urban development and urban planning. However, despite the pain and loss of human lives, people quickly forget the importance of geology in urbanization. In fact, the selection of sustainable and safe settlements, prior to urban planning and transformation, can be optimized if enough attention is paid to interdisciplinary scientific studies.

The stability and integrity of soil mechanics, slope morphology, and vulnerability to geological hazards are critical considerations when identifying secure and safe sites for urban development. Although the exact timing of many natural disasters cannot be known, it is a fact that comprehensive geological studies can determine where they may occur. It is therefore essential for geoscientists to play one of the most important roles in guiding studies for urban planning and development initiatives and taking measures to minimize the loss of human life and property. Geoscientists use remote sensing and integrated geographic information systems (GIS), as well as Multi-Criteria Decision Analysis techniques that are integrated with artificial intelligence to investigate and identify potential natural disasters in urban areas that may impact the environment as well as the residents of that urban area [17-18-19-20-21]. Based on the findings of those studies, geologists can take measures accordingly for the well-being of the residents. With these techniques, geologists conduct qualified research in many areas such as proximity to natural disasters, adaptation to climatic conditions, environmental factors that may affect potential urban development, and mitigation of their effects. The number of these studies has increased considerably in recent years, however, more studies need to be conducted. These studies and assessments serve to reduce and minimize the risks associated with geological hazards by protecting the infrastructures in urban areas through the systematic study of potential natural disasters associated with geological factors, creating a building stock resistant to these disasters, and protecting the safety of people's lives and property. Thus, geoscience and its experts should be included in urban planning and development processes, and geology should play a key role in making informed decisions about the urban ecosystem and natural disasters. In this way, before urban planning and development, decision-makers and city authorities make sure that their decisions are based on the science that is more constructive and prioritizes human health and safety.

4. Infrastructure design and construction

In a broader sense, urban infrastructure refers to the built environment, which includes structures and equipment for energy, transportation, water supply, sewage treatment, and solid waste disposal [22]. The quality of life and comfort of urban people is, in reality, determined by the state of the urban infrastructure [23]. Environmentally friendly urban infrastructure design and construction is increasingly being seen as a preferable means of providing state-of-the-art infrastructure such as transportation and utilities to densely populated urban areas. Additionally, geological factors heavily influence the design and construction of urban infrastructure, such as buildings, bridges, tunnels, highways, etc. The local geology has a major influence on infrastructure, particularly subsurface infrastructure. Therefore, understanding subsurface geology is essential to ensuring the reliability and sustainability of these structures, particularly in terms of minimizing the risks associated with geological hazards such as earthquakes, land substances, and volcanic eruptions. For instance, a volcanic eruption devastated a tiny village in Iceland in 2023 and 2024. Urban areas were evacuated in time thanks to geoscientists' diligent efforts in providing warnings in advance. As a result, while the volcanic activity caused substantial property damage, no lives were lost. Additionally, engineering solutions that are specially adapted to geological conditions are necessary to improve the strength and lifespan of urban infrastructure systems. Another example of a natural catastrophe is inundation. Geoscientists might conveniently create risk maps to assess urban areas near coasts and rivers. A recent study [24] examined 464 historic places along Türkiye's and Greece's Eastern Mediterranean coastlines. According to the findings of this study, a large number of archeological and historical sites will be inundated even under the most minimal sea level rise projections [24]. Moreover, soil liquefaction is a primary cause of structural damage in earthquakes. Liquefaction studies are critical for disaster mitigation planning, particularly in urban settings. Another study [25] investigated the socioeconomic vulnerability of Greater Chennai, India in terms of seismic hazard risk, namely soil liquefaction. According to this local study, 19.4% of the study area falls into the high-risk group [25].

The resilience and durability of the buildings and infrastructures are critical because they improve the ability to deal with the uncertain and extreme natural disasters that may occur during the extended life cycle of urban infrastructure. There is an increasing recognition that sustainability should be incorporated and implemented in geological engineering, but little emphasis has been placed on adding resilience and durability, even though sustainability and resilience share common objectives and goals [26].

5. Water resources management

While water makes up 71% of the earth's surface, only less than one percent can be used for human consumption [27]. Furthermore, less than one percent of freshwater that is available for human use is not only being consumed unconsciously but is also being contaminated recklessly. Anthropogenic activities such as agriculture, industry, and urban development can easily disrupt the hydrogeological and geochemical conditions of urban groundwater [28-29-30-31-32-33-34-35-36-37-27]. On the other hand, natural processes and parameters like lithology, groundwater velocity, recharged water quality and quantity, water's interactions with bedrock and soil components, and groundwater networks with different aquifer types influence a region's groundwater quality [38-39-27]. Hydrogeology is a branch of geosciences that studies all of these key factors and processes which is essential for urban water management efforts. Furthermore, effective floodwater management is also required for urban areas. Because urban environments are more vulnerable to the effects of heavy rainfall; thus, designing reliable stormwater infrastructure requires an interdisciplinary approach incorporating meteorological engineers and geoscientists. Moreover, it is yet unclear how climate change may affect water supplies, thus research on this topic is also necessary. The sustainable management of rainfall and stormwater runoff in urban contexts might be an opportunity for a yield of renewable water when effective flood management is on the table. Recently, local and national authorities of developed countries have been implementing small- to medium-scale sustainable urban development policies, which encourage private homes and businesses to collect rainwater and use it for greywater applications [40]. While this application has demonstrated success in Europe, Australia, North America, and some developing countries (e.g. Turkiye), it has not yet been tested in underdeveloped nations. Urbanization and urban redevelopment plans must take geological considerations into account more than ever before, given the increasing impact of climate change and the growing importance of water supplies.

6. Land use planning and environmental protection

Urban areas are the centers of human civilization, but the foundation of these civilizations rests on the science of geology which is often overlooked. Thanks to well-trained geoscientists and engineers, it is no longer a luxury to learn the geology of an urban area and to model and plan buildings accordingly. For example, in urban areas where earthquakes, sinkholes, and landslides commonly occur, buildings, which are one of the most important symbols of civilization, should be built on solid ground instead of soft alluvial soil. Prohibiting construction in a region with known valuable resources (e.g. minerals, groundwater, hydrocarbons), but mining with environmental sensitivity and responsibility, and offering the extracted natural resources to the service of humanity or taking precautions to prevent pollution by human and environmental factors while determining the availability and accessibility of those resources are all area of interests of geosciences. In order to ensure that society will have access to natural resources, land-use planning must protect this access. Multiple studies have been carried out on land use and land cover (LULC) assessments to promote sustainable urban planning through the use of remote sensing and GIS technologies. A study examined LULC analyses for sustainable urban development in Kütahya, Türkiye [41]. This study resulted in the production of LULC maps through the use of unsupervised learning techniques, GIS software, and the Landsat and Sentinel-2 remote sensing data from 2017 and 2021. The research looked at the effectiveness of the automated classifications in developing accurate LULC maps for 2017 and 2021 [41]. Another research [42] held in Tehran, Iran, aimed at investigating the urbanization process. This study used Landsat time series imagery from Google Earth dating from 1991 to 2021 and constructed LULC maps using these images. The study showed that there was a substantial rise in urban land cover, which is an indication of the fast urbanization of Tehran over the last three decades [42]. In another study, LULC analysis was carried out around the Jatibarang Reservoir in

Semarang City, Indonesia [43]. This research has employed the Nearest Neighbor Analysis as the spatial analysis tool. The fact is the results of this study have given a special and all-embracing view of the changes, patterns, and possible consequences of LULC in this specific research area [43].

Protecting access to important natural resources—if not all of them—or at the very least bringing attention to their presence has been demonstrated to be possible with the help of recognized scientific approaches [44]. Cities all across the world require these kinds of solutions now more than ever because of growing urban populations and increasing rates of land consumption [45]. As the population of cities grows and their size increases, responsible and effective environmental practices have become one of the most critical issues to avoid. For instance, the construction industry can minimize environmental impact by using more resource-friendly and low-carbon building materials based on existing geological resources. In addition to buildings and infrastructure, green spaces and parks are also needed for a sustainable life in cities. Local geology plays a critical role in determining suitable locations for parks and green spaces in urban areas that are not suitable for development, so local geology should be well studied and understood.

Soil and water pollution is likely to occur with urbanization. Geological surveys and studies play an important role in identifying pollution hotspots and the sources of pollution. Geology can also provide adequate consultancy services through the sub-disciplines of geology, such as calculating the damage caused by urbanization to the environment and taking necessary measures to protect the environment. A good understanding of geology is essential for successful and sustainable urban planning, development, and transformation. By understanding the geological landscape and prioritizing environmental protection, cities can be established that are not only functional and aesthetically pleasing but also safe, sustainable, and more inhabitable for future generations.

7. Discussions

Incorporating geosciences into processes of urban planning, development, and transformation has gained greater attention in recent years. Urbanization activities clearly demonstrate the necessity for interdisciplinary working groups and collaboration among diverse specialists, including geologists, engineers, architects, urban planners, and city officials, given that some geological factors in urban areas are susceptible to natural disasters. Urban places can be transformed into safer, more inhabitable, and more sustainable by bringing together all relevant stakeholders and utilizing all of their qualifications.

It is impossible to overestimate the importance of thorough geological surveys and studies in determining the best sites for urban development initiatives and plans for urban transformation. Precautions against natural disasters require comprehensive geological studies such as soil mechanics, slope morphology, and fault mapping, particularly for areas with known seismicity. The safety of the inhabitants is one of the most crucial factors in choosing the right locations for urbanization. In this context, geoscientists can assess and interpret potential risks of natural disasters using cutting-edge technologies like artificial intelligence, geographic information systems, and remote sensing. They can also assist people by taking the necessary precautions to mitigate the devastating effects of natural disasters.

Additionally, in regions where development is anticipated, the sustainability of infrastructure will be determined by the local geology. As a result, before planning and executing that plan, comprehensive geological studies are crucial. Furthermore, to increase the resilience of urban infrastructure systems and so guarantee the safety of life, property, and the well-being of urban residents, engineering studies that are robust as well as tailored to local geological settings are necessary.

In urban settings, anthropogenic and geogenic activities can have a substantial impact on both the quantity and quality of groundwater. To minimize dependency on groundwater alone, sustainable techniques like rainwater harvesting ought to be made mandatory in urban areas. Additionally, measures like preventing illegal well drilling and managing groundwater and rainfall runoff effectively can assist reduce the issue of water shortages in urban areas. Moreover, the scarcity, fluctuation, and contamination of water are increasing due to climate change. Extreme weather events have an adverse influence on biodiversity, sustainable development, and people's access to clean water and sanitation throughout the water cycle. Urban communities hence require a well-thought-out plan for managing their water resources.

In addition to advising where urbanization and urban transformation initiatives are most appropriate, geology is also crucial in locating contaminated areas of water and soil and identifying their potential sources. Finally, viable and sustainable urban living depends on recognizing geology's crucial role in urbanization. Considering all of these aspects, geology's often underappreciated significance must be acknowledged.

8. Conclusion

In summary, this research emphasizes that geosciences are now an inherent part of urban planning, development, and transformation, in that fundamental geological data obtained from comprehensive research may assist decision-making in reducing the potential hazards of natural disasters, improving infrastructure resilience, and serving as insurance by justifying the sustainable use of water resources. This paper also highlights the importance of an interdisciplinary approach prior to urban planning and development. Interdisciplinary workshops can address and manage urban and environmental concerns and potential hazards. Finally, geoscience education and research should take precedence in urban planning measures to develop or reconstruct safer, more resilient, and environmentally friendly future cities for future generations.

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