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Geographical Analysis of Recent Trends in Engineering Geomorphology Studies during the Period 2012-2022: Theory and Application

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ABSTRACT

The study focuses on presenting recent trends in engineering geomorphology as a branch of applied geomorphology and one of the important topics concerned with human problems and finding solutions to them, making it a practical and utilitarian science. Foreign studies have been characterized by diversity and richness in addressing research topics, unlike Arab studies. During the 1960s and 1970s, engineering geomorphology research was centered on a single research trend landslide studies. In the past ten years, however, it has expanded to cover other research directions such as fluvial engineering geomorphology, wetlands, and slopes. Geographic Information Systems (GIS) and Remote Sensing have accounted for the largest share of the applications and techniques used in engineering geomorphology research, providing more reliable data and results that enable it to compete with other disciplines.

Introduction

In recent years, the world's environments, with all their types and characteristics, have undergone numerous changes, clearly reflecting the influence of human activities and the reciprocal effects on humans themselves. This has been especially evident with the rapid advancement in science and technology and the growing demands and needs of humankind. Such progress has driven humans to build dams on rivers to control flooding, develop methods to stabilize slopes for urban expansion, and expand and modernize ports for maritime trade, among other human interventions. These actions have often resulted in rapid degradation and severe changes to environmental systems due to the misuse of resources or unplanned interactions with them. Consequently, various hazards and problems have emerged, either linked to or impacting engineering structures and human activities. It was under these circumstances that the initial seeds for the emergence of the term *Engineering Geomorphology* began to take shape[(1)].

Engineering geomorphology is a branch of applied geomorphology and one of the important topics that give geography a practical, applied dimension, making it a science concerned with human problems and focused on finding solutions to them. It also provides scientific support for engineering decision-making, particularly in planning, design, and construction (Fookes et al., 2007).

Engineering geomorphology provides essential data for Geospatial and geotechnical projects, and consequently for civil engineering. It deals directly with geomorphology, engineering geology, and soil mechanics, with the prerequisite of having a database on surface water, surface processes, and land resources. This is followed by the study and analysis of changes in landforms and the clarification of their impact on engineering structures (Figure 1). Accordingly, it plays a key role in offering solutions to problems that may arise, thereby assisting decision-makers in making informed choices.

Geomorphological Engineering is concerned with the study of the morphological characteristics of the Earth's surface and geomorphological phenomena, as well as the processes responsible for their formation from an engineering perspective. It combines geomorphological knowledge in studying dynamic landforms and their potential impacts on engineering structures and human activities. This is achieved through geotechnical assessments of the hydrological, hydraulic, mechanical, and morphological properties of the Earth's surface (Klimes & Blahut, 2017).

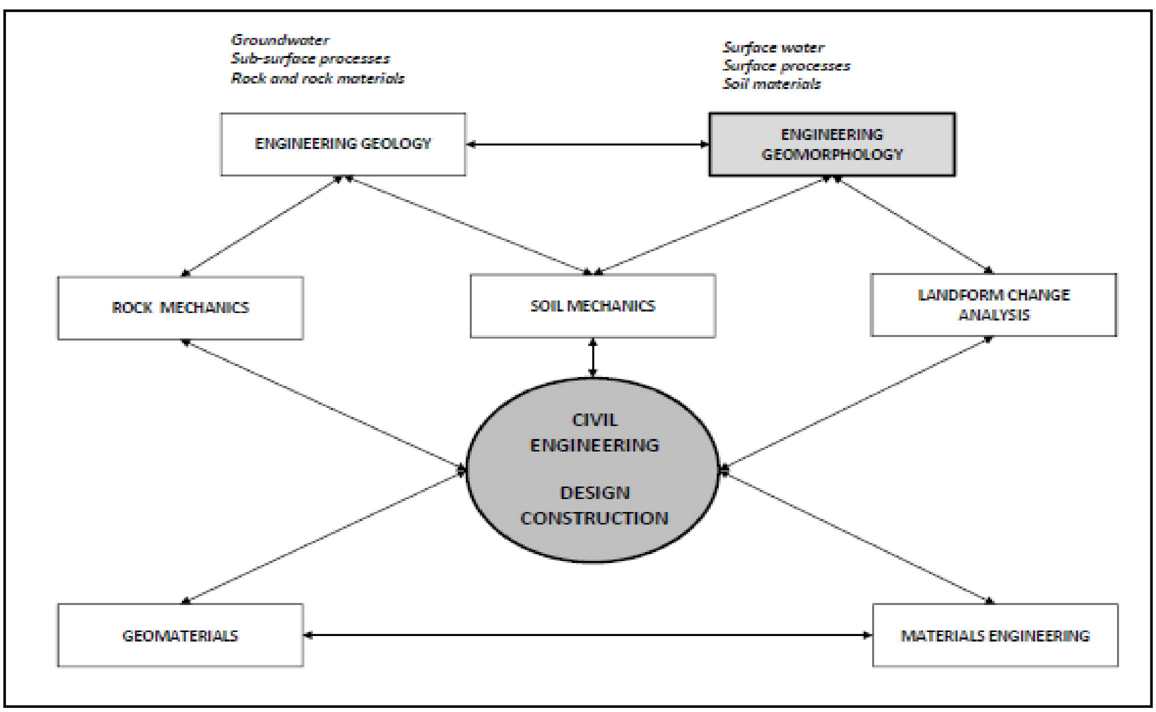

Figure 1. Schematic relationship between engineering geomorphology, engineering geology, and civil engineering (adapted from Fookes,1997).

[1]) There is a close relationship between the construction of structures, roads, and urban areas on the one hand, and the natural landform-shaping factors on the other. Natural factors directly and indirectly influence their locations and various characteristics (Ali, 2000), and the reverse is also true, as the relationship is mutual and interconnected.

Previous Studies:

Previous studies closely related to the subject of this research have been characterized by great diversity worldwide, ranging from theoretical studies on the concept of engineering geomorphology, its historical development, and its research fields, to applied studies on topics of interest within these fields. Examples include, but are not limited to:

- **Brunsden et al. (1975)**, titled *Geomorphological Mapping in Highway Engineering Design*. This study identified eight objectives for geomorphological surveys in highway engineering, in the context of both small- and large-scale maps, using case studies from Nepal and South Wales.
- **Griffiths & Hearn (1990)**, titled *Engineering Geomorphology from a United Kingdom Perspective*. This research reviewed the development of engineering geomorphology as an applied science in the UK between the 1970s and 1990s, and provided recommendations on the importance of engineering geomorphology and its potential contributions to civil engineering projects.
- **Giardino & Marston (1990)**, titled *Engineering Geomorphology: An Overview of Changing the Face of the Earth*. This study addressed the role of engineering geomorphology in examining various research fields and discussed the future of engineering geomorphology.
- **Fookes et al. (2007)**, titled *Engineering Geomorphology: Theory and Practice*. This book covers fundamental geomorphological concepts and Earth surface systems (slopes, rivers, coasts), along with the associated hazards that necessitated the development of engineering projects. It also examines geomorphological processes that may affect engineering works and the available techniques to address them.
- **Parry & Hart (2012)**, titled *Engineering Geomorphological Mapping for Landslide Hazard Assessment in Hong Kong*. This study discussed the use of engineering geological models in conjunction with engineering geomorphological maps to assess landslide hazards, aiming to produce more accurate results free from uncertainty.

Arab Regional and Local Studies: These are characterized by their limited scope (within the researcher's knowledge), as the term *engineering geomorphology* did not appear in the titles of Arab research papers or academic theses except for the first time in **Soliman (2013)**, titled *The Scope of the International Coastal Road between Damietta and Rosetta: A Study in Engineering Geomorphology*. This study examined the natural characteristics within the study area, discussed the natural constraints affecting the route of the International Coastal Road, analyzed the prevailing geomorphological processes, and concluded with an engineering geomorphological assessment of the road's scope in light of current hazards and future projections.

Upon tracing its development, the term appeared again in **2014** in a study titled *The Geomorphological Assessment of Human Interventions in the Baltim Beach Area on the Nile Delta Coast of Egypt: A Study in Applied Engineering Geomorphology*. This research evaluated the human impact as a geomorphological factor, using methods to monitor changes in the area from 1909 to 2011. It clarified the impact of the High Dam construction on the coast, the protection measures applied, and the resulting negative changes. Another example is **Shalaby (2021)**, titled *The Engineering Geomorphology of the Mokattam Plateau, East Cairo*. This study addressed the changes the plateau experienced due to human intervention, examined the slopes and the forces causing landslides, and presented a model for simulating rock falls in certain slope locations on the plateau using the Rock fall software.

Based on previous studies, research fields in engineering geomorphology are diverse, focusing on the study of different environments of landforms, using geoinformatics techniques, with an emphasis on finding solutions and addressing the challenges and constraints resulting from changes in the morphological characteristics of the Earth's surface due to human activities. These fields can be classified as follows:

- Coastal Engineering Geomorphology

- Fluvial and Wetland Engineering Geomorphology
- Slope Engineering Geomorphology
- Karst Engineering Geomorphology
- Arid Land Engineering Geomorphology
- Engineering Geomorphology of Economic Activities

Significance of the Study:

The importance of studying recent trends in engineering geomorphology lies in its nature as a practical and utilitarian applied science concerned with examining the relationship between geomorphological processes, landforms, and various human activities. The dynamic landscape of the Earth's surface has necessitated reliance on engineering geomorphology to assist stakeholders, decision-makers, and planners in the field of engineering projects by providing highly reliable results and protection measures that reduce the ongoing impact of geomorphological hazards on such human-made structures.

Objectives of the Study:

The study aims to survey, compile, and quantitatively classify the scientific research that has addressed engineering geomorphology during the period (2012–2022), tracing its temporal development, spatial distribution, and identifying and analyzing the methodological trends of its topics. It focuses on presenting the modern techniques and methods used in addressing these topics, in addition to producing results useful for their evaluation, along with recommendations that serve researchers and those interested in such studies.

Study Methodology, Approaches, and Techniques:

To achieve the above objectives, the study adopted the descriptive-analytical method to define the concept of engineering geomorphology, its research fields, and to analyze and interpret them with the aim of comparison and deriving results that can be generalized and applied. The study also employed certain approaches, such as the historical approach in examining the historical development of the term *engineering geomorphology* and tracing its temporal evolution according to its fields, and the thematic approach in classifying the scientific research that addressed the study's subject, the trends of its topics, and the presentation of its applications. In addition, the study utilized various statistical and cartographic techniques to present and analyze the study's data in the form of tables, charts, and maps.

Study Sources:

The study relied on global databases—**Scopus** and **Web of Science**—in addition to the Egyptian Knowledge Bank (*Dar Almandumah*) and the Egyptian Universities Libraries Consortium to compile engineering geomorphology studies from both foreign and Arab journals.
Accordingly, the research was classified into the following topics:

First: The Historical Evolution of the Term Engineering Geomorphology:

Engineering disciplines have significantly contributed to understanding geomorphological processes, the formation and evolution of geomorphological features, and the potential hazards they pose to engineering structures. The relationship between geomorphology and civil engineering first emerged in 1923 (Terzaghi, 1925). Gillman (1937), in his study on the impact of morphological changes in the Earth's surface on engineering sites and structures, pointed out the scarcity of studies clarifying the relationship between the two disciplines: geomorphology and civil engineering.

Despite this observation, no collaboration occurred between the two fields for 23 years after this study—until the 1960s, when a significant study emerged. This study addressed the geomorphology of landslides and their relationship with the engineering properties of soil mechanics and hydrology, as well as their impact on engineering structures, especially roads and bridges. Civil engineering relied on geomorphology through studying the historical development of landslide dynamics, identifying the main causes leading to them, and analyzing past climatic conditions.

By the late 1960s, there was significant academic interest in linking geomorphology with engineering through a number of studies [(2)], which also focused on the study of landslides. These studies relied, from a geomorphological perspective, on drawing topographic cross-sections of slopes to determine slope angles that ensure stability and reduce landslide phenomena, as well as the associated hazards and problems. In addition, they produced geological maps based on field studies and the interpretation of aerial photographs. Here, the importance of engineering geological maps emerged in studying soil behavior, engineering properties, landslide maps, and more.

The British geologist Fookes advocated for the essential integration of geomorphology into engineering geology. He emphasized the use of aerial photographs in creating and designing engineering geological maps, stressing the need to combine engineering geology with the principles of geomorphology.

Indeed, following this development, interest grew in combining the two disciplines, leading to the first engineering geomorphological map in 1974. These maps documented the stages and manifestations of changes caused by landslides along The Prince Llewellyn Road (Figure 2). This marked the emergence of the first study explicitly framed as "Engineering Geomorphology" in 1974 (Lee & Fookes, 2015).

Subsequently, several studies emerged that explicitly addressed the term "Engineering Geomorphology" or explored the relationship between geomorphology and civil engineering. This marked the gradual acceptance of Engineering Geomorphology as a recognized discipline within civil engineering, encompassing both terrestrial and marine applications (Laimer, 2021).

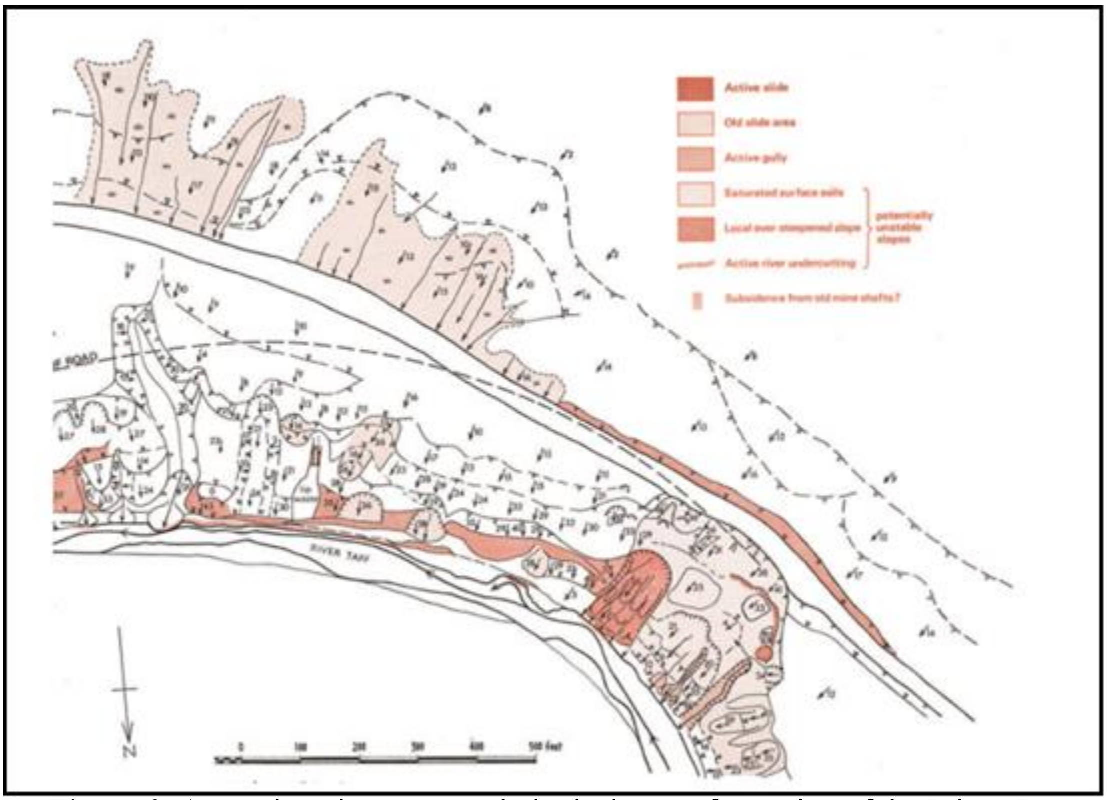

Figure 2. An engineering geomorphological map of a section of the Prince L. Lewellyn area in South Wales (Dearman & Fookes, 1974).

2) - Skempton, A.W. 1964. Long-term stability of clays slopes.
- Skempton, A.W. & Petley, D.J. 1967. The shear strength along structural discontinuities in stiff clays.
- Hutchinson, J.N. 1967. The free degradation of London Clay cliffs.
- Hutchinson, J.N. 1970. A coastal mudflow on the London Clay cliffs at Beltinge.

Nonetheless, its development progressed slowly from the introduction of the aforementioned applications in the 1970s through the 1990s, with a particular focus on landslides and their relevance to road construction projects and the planning of geotechnical earthworks. This slow advancement and the limited acceptance of the term *engineering geomorphology*—contrary to expectations—can be attributed to its lack of recognition among civil engineers. One key reason was that the techniques employed in the design and preparation of engineering geomorphological maps during this period were already familiar to civil engineers, thereby reducing the perceived need for input from geomorphologists. Furthermore, these maps were generally consulted only during the initial phases of projects, and geomorphologists were often regarded as having insufficient familiarity with engineering standards (Griffiths & Hearn, 1990).

More than forty years after the initial production of geomorphological maps for landslides, *engineering geomorphological* studies have increased significantly, to the extent that the field has become an independent sector in the United Kingdom and several other countries. However, in Central Europe, the discipline has so far received only limited attention as an applied Earth science. Geomorphological approaches are still insufficiently employed in civil engineering (Laimer, 2021).

Secondly: Identification of Databases and Selection of Scientific Journals and Sources for the Study:

To identify recent global trends in engineering geomorphology research, a comprehensive survey was conducted of all studies closely related to the subject, whether employing the term *engineering geomorphology* directly or utilizing a range of relevant and closely associated keywords. This was carried out using the largest international search engines and databases, namely **Scopus** and **Web of Science**. The survey resulted in the selection of eleven journals, based on global evaluation criteria(3) (Table 1) and (Figure 3), as well as their relevance to the study topic. Given that the research subject overlaps with other Earth science disciplines, four journals specializing in Earth sciences were selected(4), along with seven focusing on geomorphology and its processes. The final dataset comprised a total of **216** research papers.

Following the same methodology, recent trends in studies of engineering geomorphology were identified locally by conducting a comprehensive survey of scientific research published in Arab journals. The Egyptian Knowledge Bank (EKB) database, particularly Dar Almandumah, was utilized, in addition to searching the Egyptian Universities Libraries Consortium (EULC) website to identify theses related to the study topic. The search resulted in

3) **The global evaluation criteria were as follows:**
- **Impact Factor** — a scientific indicator reflecting the average annual number of citations received by articles published in a given journal. A higher impact factor denotes greater prestige and significance of the journal. All journals examined in this study have impact factors ranging from moderate to high.
- **SJR (SCImago Journal Rank)** — a metric that indicates the scientific influence of journals, based on their citation rate and the extent to which they are referenced. It is particularly important for ranking journals globally according to the most recent classification for the year 2021.
- **Quartile Ranking (Q1, Q2)** — all journals analyzed in this study fall within the first and second quartiles, which represent the highest-ranking journals worldwide. Journals are classified from Q1 to Q4 according to their relative importance.
- **H-Index** — a metric measuring the relationship between the number of published papers and the number of citations they have received, reflecting both research productivity and citation impact.

4) The study established the definition of engineering geomorphology, its evolution, and its methodology based on research published in the following journals: The Arab Journal of Earth Sciences, Engineering Geology, Bulletin of Engineering Geology, and Quarterly Journal of Engineering Geology. The findings derived from these sources were then applied to other journals to select the most relevant topics closely related to the study's subject.

the selection of 12 scientific journals[(5)], with the survey covering (17) research papers and (9) academic theses.

Table 1. International journals selected to examine recent trends in engineering geomorphology studies according to global evaluation criteria during the period (2012–2022)

No	Journal	IF	Quartile	SJR	H-INDEX	Publisher	Country	ISSN`
1	Geomorphology	4.406	Q1	1.21	171	Elsevier	Netherlands	0169555X, 1872695X
2	Earth surface processes and landforms	3.956	Q1	1.19	134	John Wiley and Sons Lad	United Kingdom	1979337
3	Physical Geography	2.075	Q2	0.45	41	Taylor and Francis Ltd	United Kingdom	2723646
4	Landslides	6.153 (2021)	Q1	1.92	89	Springer Verlag	Germany	1612510X 16125118
5	Progress in Physical Geography: Earth and Environment	4.283	Q1	0.89	108	SAGE Publication Ltd	United Kingdom	03091333, 14770296
6	Natural hazard and earth system sciences	4.58	Q1	1.14	107	European Geosciences Union	Germany	15618633, 16849981
7	Applied Geography	4.732	Q1	1.17	108	Elsevier BV	Netherlands	1436228
8	Arabian Journal of Geoscience	1.985	Q2	0.41	58	Springer Verlag	Germany	18667511, 18667538
9	Engineering Geology	6.902	Q1	2.29	150	Elsevier	Netherlands	00137952
10	Bulletin of Engineering Geology	4.13	Q1	1.08	68	Springer Verlag	Germany	14359529, 14359537
11	Quarterly of Engineering Geology	1.727	Q2	0.42	44	Geological society of London	United Kingdom	14709136

Prepared by the researcher based on data from: https://www.scimagojr.com/journalsearch.php?q=geography

Analysis of the comprehensive survey of the total number of engineering geomorphology studies published in international journals—presented in Table 2 and Figure 4—reveals that the journal *Geomorphology* accounted for 41.7% of all studies, with a total of 90 papers. It was followed by *Earth Surface Processes and Landforms*, which represented 14.4% of the total, with 31 papers. Together, these two journals comprise more than half of the studies examined

[5]) The distribution of research articles was as follows: The Arab Geographical Journal contributed (5) studies, Al-Anbar University Journal for Humanities (2) studies, while Fayoum University Journal of the Faculty of Arts, Journal of Research at the College of Basic Education, University of Mosul, Suez Canal University Journal of Arts and Humanities, Mansoura University Journal of the Faculty of Arts, Zagazig University Journal of the Faculty of Arts, Geographical Letters, Kuwait University, Journal of Humanistic and Literary Studies, Faculty of Arts, Kafr El-Sheikh University, Alexandria University Journal of the Faculty of Arts, and Tanta University Journal of the Faculty of Arts each contributed one study. Additionally, one study was sourced from a symposium published by the Ministry of Public Works and Housing.

within this research domain[6]. The predominance of publications in these two journals is attributed to their primary focus on research topics directly aligned with the scope of engineering geomorphology. In contrast, the number of studies in both *Engineering Geology* and *Progress in Physical Geography* was markedly lower, each representing only 1.4% of the total. This decline can be explained by the specific scope of these journals: the former primarily addresses geological studies in relation to civil engineering, whereas the latter focuses on environmental aspects of geomorphological research.

Figure 3. International journals selected to examine recent trends in engineering geomorphology studies according to global evaluation criteria.

[6]) Both journals are dedicated to publishing a wide range of geomorphological topics, whether theoretical or applied, with the subject of this study falling well within their scope and core focus. They are also distinguished by their consistent publication record and high volume of output.

With regard to the Arabic sources presented in Table 3, it is evident that the research trend under study is generally limited in volume, ranging from 17 scientific papers to 9 academic theses. Within this body of work, *The Arab Geographical Journal* accounted for the largest share, publishing five papers—representing 29.4% of the total research articles in Arabic journals and 19.2% of the total Arabic sources.

Although the representation of this research trend in Arabic sources is relatively low, the topics addressed are diverse. They cover the role of geomorphological processes, geomorphological hazards affecting engineering structures such as roads and urban centers, and the impact of human interventions on geomorphological processes and landforms. These topics align with recent research trends in the field of engineering geomorphology as reflected in international journals.

To provide a clearer perspective on the research trend under investigation, studies in engineering geomorphology were classified according to their areas of focus and scope into seven research domains: fluvial engineering geomorphology, coastal engineering geomorphology, slope-related studies, karst geomorphology, arid land geomorphology, economic activity studies, and other studies—encompassing theoretical research on the subject as well as interdisciplinary topics linking Earth sciences. These studies were identified, classified, and examined in terms of their temporal development, research trends, and the most important applications employed in their analysis, as will be discussed later.

Table 2. Numerical and percentage distribution of the total engineering geomorphology studies in international journals during the period (2012–2022)

Journal	Number	٪
Geomorphology	90	41.7
Earth Surface Processes	31	14.4
Physical Geography	4	1.8
Landslides	27	12.5
Progress in Physical Geography	3	1.4
Natural Hazards and Earth Sciences	26	12.0
Applied Geography	4	1.9
Arabian Journal of Geosciences	16	7.4
Engineering Geology	3	1.4
Engineering Geology Bulletin	4	1.8
Quarterly Journal of Engineering Geology	8	3.7
Total	216	100

Prepared by the researcher based on data from:
https://www.scimagojr.com/journalsearch.php?q=geography

Table 3. The numerical and relative distribution of the total studies on engineering geomorphology in Arabic sources during the period (2012–2022)

Arabic Sources	Number	٪
Scientific Research Papers	**17**	**65.4**
Academic Theses and Dissertations	**9**	**34.6**
Total	**26**	**100**

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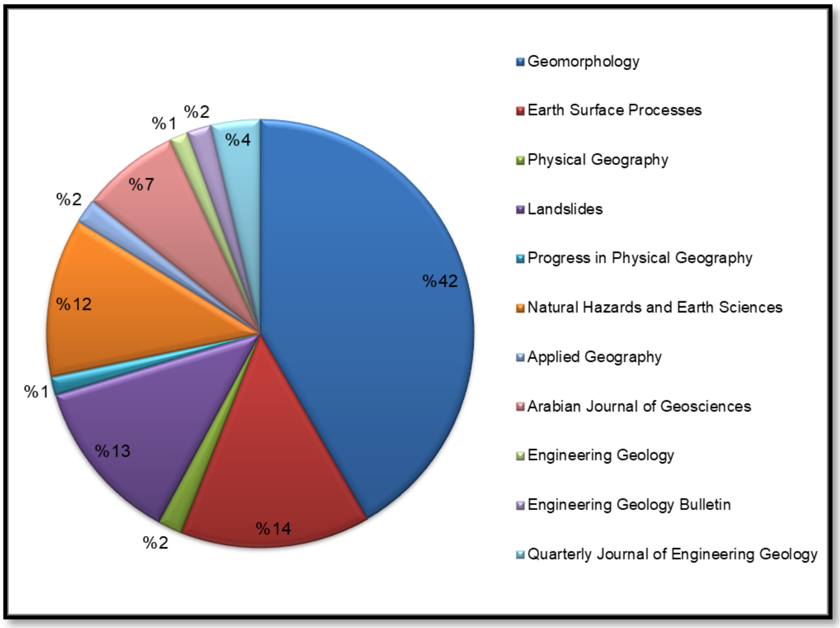

Prepared by the researcher based on Table 2.

Figure 4. The relative distribution of the total studies on engineering geomorphology in foreign journals during the period (2012–2022)

Third: Recent Trends in the Fields of Engineering Geomorphology during the Period (2012–2022):

The research domains in engineering geomorphology are diverse, given their engagement with various natural environments. These domains will be examined and analyzed, and classified according to the selected foreign and Arabic scientific journals. Their development and geographical distribution will be tracked through the following points:

1- The numerical and relative distribution of engineering geomorphology studies according to their research domains during the period (2012–2022):

An analysis of recent trends in engineering geomorphology studies, based on their research domains in foreign and Arabic journals as presented in Table 4 and Figure 5, reveals the following:

-The total number of studies addressing fluvial and wetland engineering geomorphology amounts to 118 papers, representing 48.8% of the total research output—approximately half of all studies produced in this field. The largest share was published in the *Geomorphology* journal with 64 papers, followed by *Earth Surface Processes and Landforms* with 28 papers.

-Studies focusing on slope engineering geomorphology rank second in terms of research output, totaling 63 papers, which accounts for 26% of the total. The highest number was recorded in the *Landslides* journal with 27 papers, followed by *Geomorphology* with 10 papers, and *Natural Hazards and Earth System Sciences* with 8 papers.

-Studies related to the field of coastal engineering geomorphology account for approximately 9.9% of the total research output, with 24 papers in total. The Geomorphology journal alone comprises about 50% of the total research in this domain, followed by Arabic journals and academic theses, each with 4 papers, together representing 30.7% of the total research from Arabic sources. This percentage reflects the primary research direction pursued by Arabic-language sources.

-The number of scientific studies in other research domains is comparatively lower, with the smallest share observed in the field of arid-land engineering geomorphology, totaling only 3 papers, while the largest among them appears in theoretical studies and interdisciplinary research between Earth sciences and their relation to management and development, totaling 22 papers.

From the above, it can be concluded that there are clear research tendencies toward certain fields over others, with a primary concentration on two main domains: fluvial and wetland engineering geomorphology, and slope engineering geomorphology. This trend is unsurprising; as indicated in the earlier discussion on the historical Evolution of the term "engineering geomorphology," the field initially focused on the study of slopes, which represented the dominant research direction at the time. However, a subsequent decline in interest in this area has shifted it to second place, while fluvial and wetland engineering geomorphology has risen to occupy the leading position. This shift has been supported by researchers' interest in addressing topics related to rivers—particularly the impacts of constructing dams, barrages, and bridges on fluvial processes—as well as by the broad scope and wide geographical distribution of this field at the global level.

Table 4. The numerical and relative distribution of engineering geomorphology studies according to their research domains during the period (2012–2022)

Journal	Fields of Engineering Geomorphology							Total
	Coastal Engineering Geomorphology	Fluvial and Wetland Engineering Geomorphology	Slope Engineering Geomorphology	Karst Engineering Geomorphology	Engineering Geomorphology of Economic Activities	Arid-Land Engineering Geomorphology	Others	
Geomorphology	12	64	10	-	-	1	3	90
Earth Surface Processes	1	28	-	1	-	-	1	31
Physical Geography	1	1	2	-	-	-	-	4
Landslides	-	-	27	-	-	-	-	27
Progress in Physical Geography	-	1	1	1	-	-	-	3
Natural Hazards and Earth Sciences	1	9	8	1	1	-	6	26
Applied Geography	-	4	-	-	-	-	-	4
Arabian Journal of Geosciences	1	7	6	-	1	1	-	16
Engineering Geology	-	1	2	-	-	-	-	3
Engineering Geology Bulletin	-	-	2	-	-	-	2	4
Quarterly Journal of Engineering Geology	-	-	1	-	3	-	4	8
Arabic Journals	4	-	4	-	1	-	5	14
Academic Theses	4	3	-	1	2	1	1	12
Total	24	118	63	4	8	3	22	242

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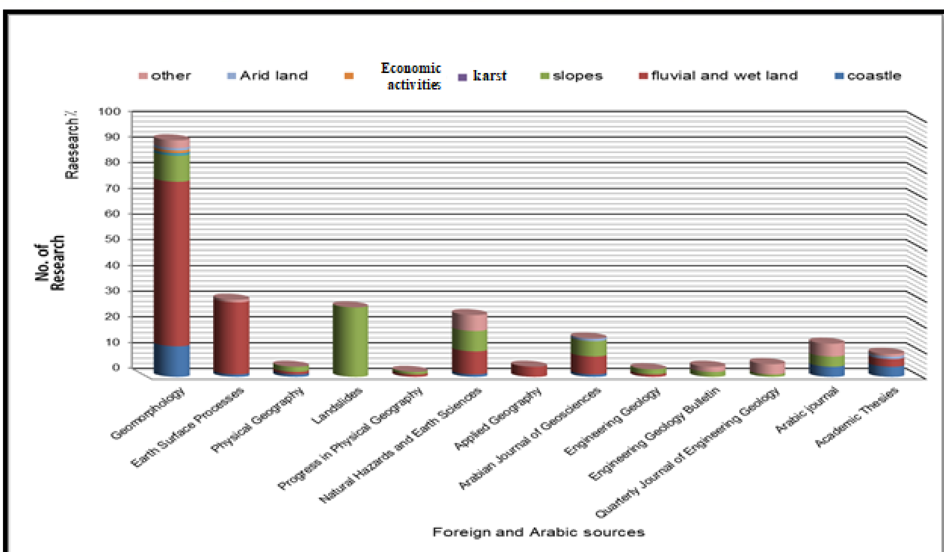

Prepared by the researcher based on Table 4.

Figure 5. Numerical Distribution of Engineering Geomorphology Studies according to the main research fields during the Period 2012-2022

2-The Evolution of Engineering Geomorphology Studies According to Their Research Fields (2012-2022):

The development of engineering geomorphology studies, as illustrated in Table 5 and Figure 6, reveals the following:

- The distribution of scientific research during the surveyed period fluctuated between increases and decreases. In 2012, the number of published studies reached 15, accounting for 6.2% of the total. However, this number dropped significantly the following year, in 2013, which recorded the lowest number of studies with only 10 publications, representing 4.1%. The number then rose again in 2014, with 17 studies (7.1%). Between 2015 and 2019, the percentages converged noticeably, ranging between 9.1% and 10.7%. This fluctuation continued until 2022, with 2021 being the year with the highest number of published studies, reaching 30 (12.4%). Despite these variations, this distribution indicates an overall increasing trend in research output in recent years.

- This fluctuation applies not only to the total number of studies but also extends to the level of research fields within engineering geomorphology. There are years in which no studies were published in certain fields, and other years in which most research fields took the lead. For example, in 2012, four research fields were not addressed at all, whereas in 2019, six out of the total seven research fields were recorded, with 26 published studies.

-Studies in the three research fields—fluvial, slope, and coastal geomorphology—consistently ranked highest in terms of the number and proportion of publications across all the years examined, despite year-to-year fluctuations in their output. These fields have been characterized by continuity up to the present day. In contrast, a marked decline was observed in certain fields, such as karst engineering geomorphology, which saw its first study published in 2015 but witnessed no further research after 2019. Conversely, engineering geomorphology of arid lands emerged more recently in 2019 and continued until 2022, although the number of its published studies did not exceed three.

Table 5. Development of Engineering Geomorphology Studies According to Their Research Fields During the Period (2012–2022)

Year	Coastal Engineering Geomorphology	Fluvial and Wetland Engineering Geomorphology	Slope Engineering Geomorphology	Karst Engineering Geomorphology	Engineering Geomorphology of Economic Activities	Arid-Land Engineering Geomorphology	Others	Total
2012	1	10	4	-	-	-	-	15
2013	3	3	3	-	-	-	1	10
2014	2	9	3	-	-	2	1	17
2015	1	11	9	1	-	1	3	26
2016	3	13	5	2	-	1	3	27
2017	2	9	6	-	-	3	2	22
2018	2	8	10	-	-	-	3	23
2019	4	9	9	1	1	-	2	26
2020	3	11	1	-	-	1	2	18
2021	2	19	4	-	1	-	4	30
2022	1	16	9	-	1	-	1	28
Total	24	118	63	4	3	8	22	242

Prepared by the researcher based on
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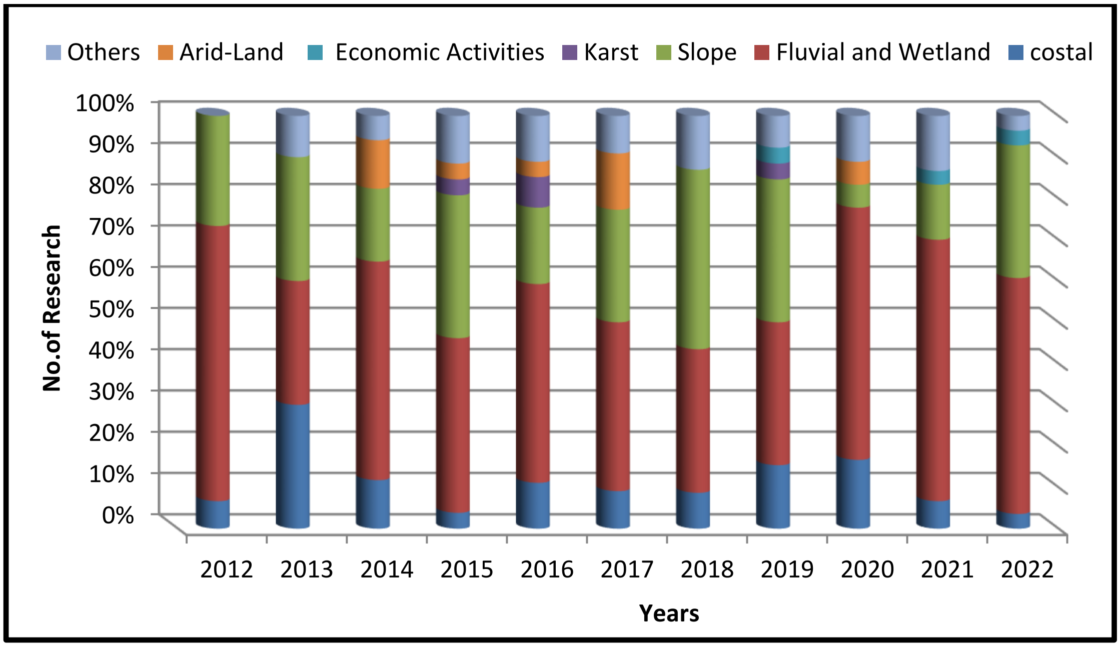

Prepared by the researcher based on Table 5.

Figure 6. Development of Engineering Geomorphology Studies According to the Main Research Fields During the Period (2012–2022)

3- Geographical Distribution of Engineering Geomorphology Studies During the Period (2012–2022):

An analysis of the distribution of recent trends in engineering geomorphology studies across continents and countries, as shown in Table 6 and Figures (7, 8, and 9), reveals several key findings summarized as follows:

- Asia ranks first, accounting for 32.7% of the total research articles published in international journals, with 79 studies. The majority of these studies are concentrated in China and India, with 39 and 11 publications, respectively. In China, the Yangtze and Yellow Rivers alone accounted for nearly 75% of the total published research. The dominant research focus in these countries has been on river studies, encompassing several subtopics such as the impact of engineering structures on geomorphological processes, changes in river morphology, dam removal and its role in altering channel morphology. Landslide studies ranked second in research focus, with key topics including the relationship between roads and landslides using multidisciplinary techniques and high-resolution satellite imagery, as well as the mutual impact between engineering structures and landslide movements.
- Europe ranks second in terms of the total research articles published in international journals, with 67 studies, representing 27.7% of the total. These studies were distributed across 17 countries, with Italy and Spain each accounting for the largest share, at 17 studies apiece. The prevailing research focus in European countries has been on slope studies, particularly the analysis of landslides, their causes, and impacts, which constituted more than 80% of all studies conducted in Europe. This was followed by river studies, which ranked second in research focus. Notably, one of the research titles indicated the application of drone technology and the integration of Geographic Information Systems (GIS) with remote sensing techniques.
- North America ranked third in terms of the number of studies, with a total of 36 publications, representing 15.0% of the total. The United States accounted for the vast majority—89%—with 32 studies. River studies were the predominant research focus in the continent, comprising more than 95% of all topics applied to North American countries, particularly the United States. Additionally, two studies explicitly mentioned the use of drone technology in examining river channels, erosion and deposition processes, and morphological modifications. Another study addressed an engineering effort to establish

protective measures aimed at safeguarding coastal properties without causing harm to them.

- Africa ranked fourth in terms of the number of studies, with 22 publications, representing 9.2% of the total research published in both international and Arabic journals. Egypt topped the list of African countries, with 17 studies, accounting for 77.3% of the continent's total and 7.1% of the overall number of studies worldwide. The predominant research focus in Egypt was on coastal studies, particularly examining the impact of human interventions on coastal geomorphology.

- The topics addressed in the 22 "other" studies, representing 9.2% of the total research conducted worldwide, varied between theoretical studies and those covering more than one continent, encompassing all the research fields examined. Accordingly, this category holds the same ranking as Africa, occupying fourth place.

-Australia (including Australia and New Zealand) and South America recorded the lowest numbers of studies, ranking fifth and sixth among the world's continents, with shares of 4.6% and 1.7%, respectively.

Table 6. Geographical distribution of engineering geomorphology studies in foreign and Arabic sources during the period (2012–2022)

Country	Number of studies	%	Country	Number of studies	%	Country	Number of studies	%
China	39	16.1	**Italy**	17	7.1	**Canada**	3	1.2
India	11	4.5	**Spain**	17	7.1	**Mexico**	1	0.4
Vietnam	4	1.7	**Switzerland**	4	1.7	**Total for North America**	**36**	15.0
Pakistan	1	0.4	**Portugal**	1	0.4	**Argentina**	2	0.8
Taiwan	7	3.0	**Hungary**	1	0.4	**Colombia**	1	0.4
Nepal	1	0.4	**Ireland**	1	0.4	**Peru**	1	0.4
Hong Kong	1	0.4	**Belgium**	1	0.4	**Total for South America**	**4**	1.7
Japan	1	0.4	**Czech Republic**	1	0.4	**Total for Australia**	11	**6.4**
Laos	1	0.4	**Romania**	2	0.8	**Algeria**	2	0.8
Philippines	1	0.4	**Greece**	3	1.2	**Morocco**	1	0.4
Saudi Arabia	5	2.1	**Turkey**	5	2.1	**Ethiopia**	1	0.4
Malaysia	1	0.4	**United Kingdom**	1	0.4	**Egypt**	17	7.1
United Arab Emirates	1	0.4	**Germany**	1	0.4	**Burkina Faso**	1	0.4
Iran	1	0.4	**Poland**	2	0.8	**Total for Africa**	**22**	**9.2**
Iraq	3	1.2	**Netherlands**	3	1.2	**Others**	22	**9.2**
Oman	1	0.4	**Austria**	1	0.4	**Grand Total**	**242**	**100**
Total for Asia	**79**	32.6	**Total for Europe**	**67**	27.7			
France	6	2.5	**United States of America**	32	13.4			

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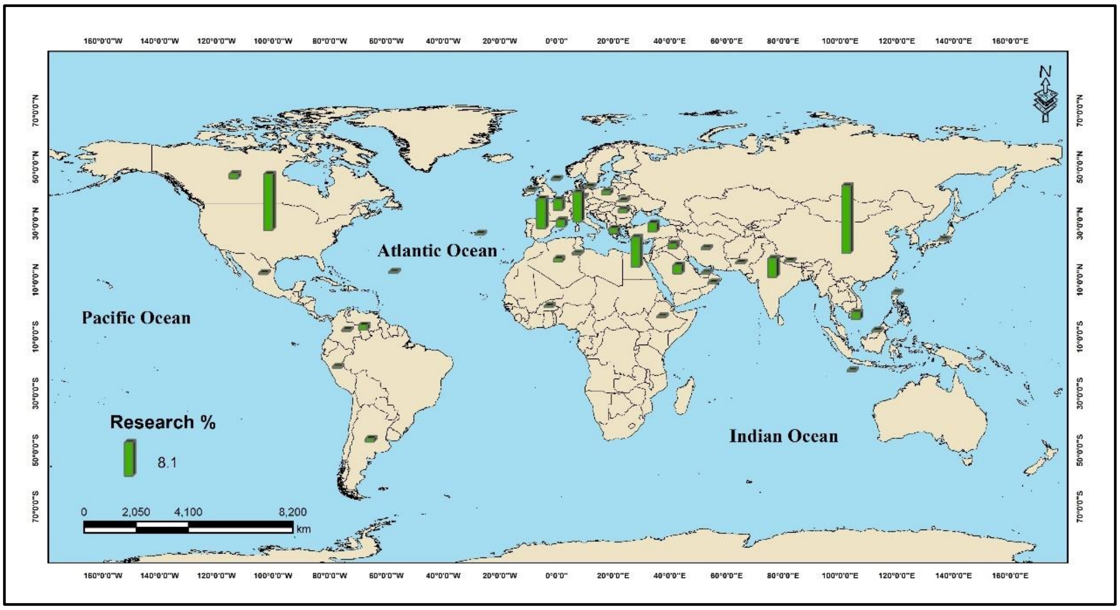

Figure 7. Distribution of engineering geomorphology studies in foreign and Arab sources across the world's continents during the period (2012-2022)

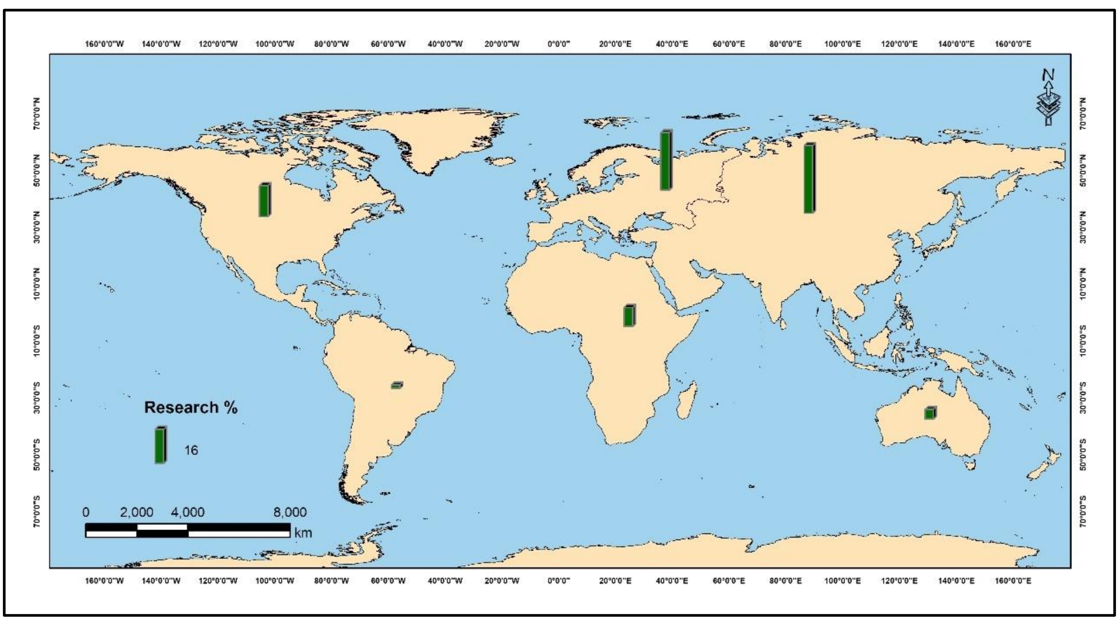

Figure 8. Distribution of engineering geomorphology studies in foreign and Arab sources at the level of countries of the world during the period (2012-2022)

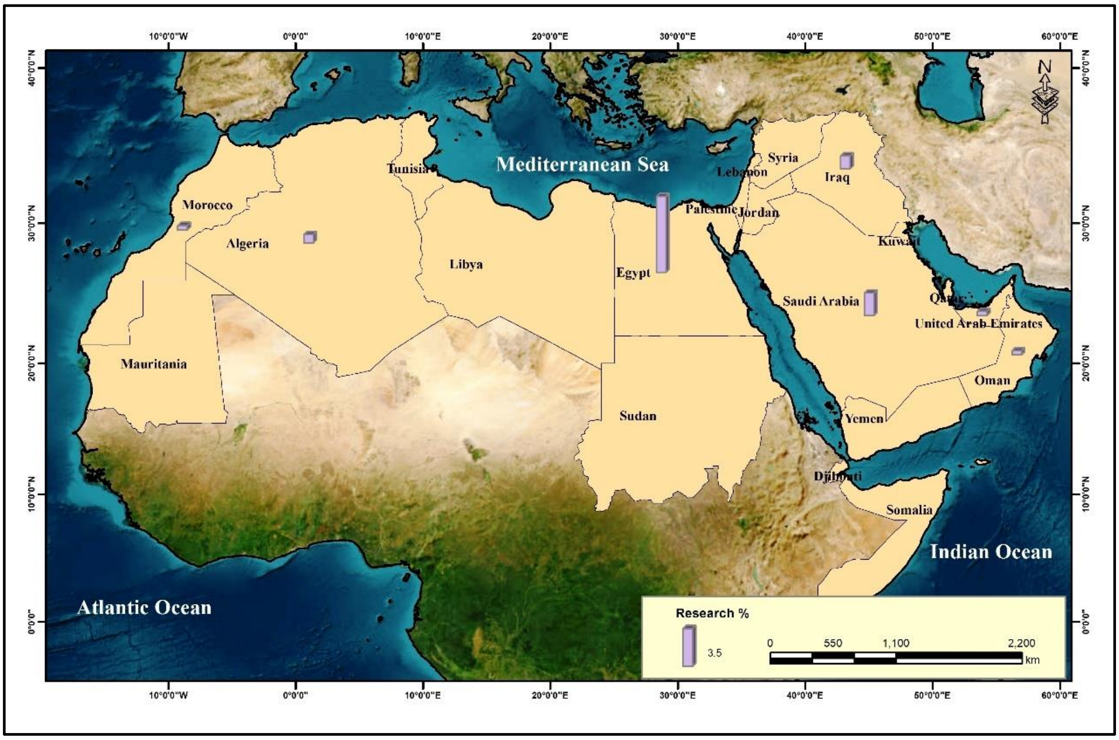

Figure 9. Distribution of engineering geomorphology studies at the level of Arab countries during the period (2012-2022)

Fourth: Modern Methodological Trends in the Fields of Engineering Geomorphology

1- Applications of Engineering Geomorphology in Slope Studies

A- The study by Clayton et al. (2017), entitled *"Engineering Geomorphological Interpretation of the Mitchell Creek Landslide, British Columbia, Canada"*, represents the most recent assessment of the Mitchell Creek Landslide (MCL) in northern British Columbia (Plate 1). This case serves as an excellent example of the historical analysis of a large landslide from an engineering geomorphology perspective. The analysis relied on aerial photographs taken over approximately 20-year intervals (1992–2010), supplemented by field investigations conducted between 2008 and 2014.The study documents four key aspects of the engineering geomorphological assessment Topographic evolution, Slope morphology, Deformation characteristics, Displacement behavior. Four geomorphological zones were identified based on the current landslide geometry, and deformation features within these zones were mapped and interpreted over time. It was observed that the extents of these zones changed only slightly over the documented history of the landslide, and movement rates estimated from aerial imagery remained consistent over the past sixty years. The retreat of the Mitchell Valley Glacier appears to have played a significant role in initiating the landslide, as the ice mass retreated and increased the slope's freedom of movement. The study concludes by advocating for a **multifaceted approach** to engineering geomorphology, combining historical aerial imagery, digital photogrammetric modeling, and geomorphological mapping (Figure 10), in order to develop a robust understanding of landslide behavior.

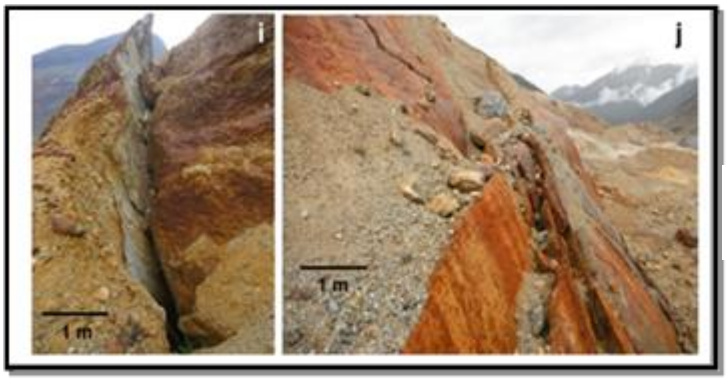

Plate 1. Mitchell Creek Landslide Area

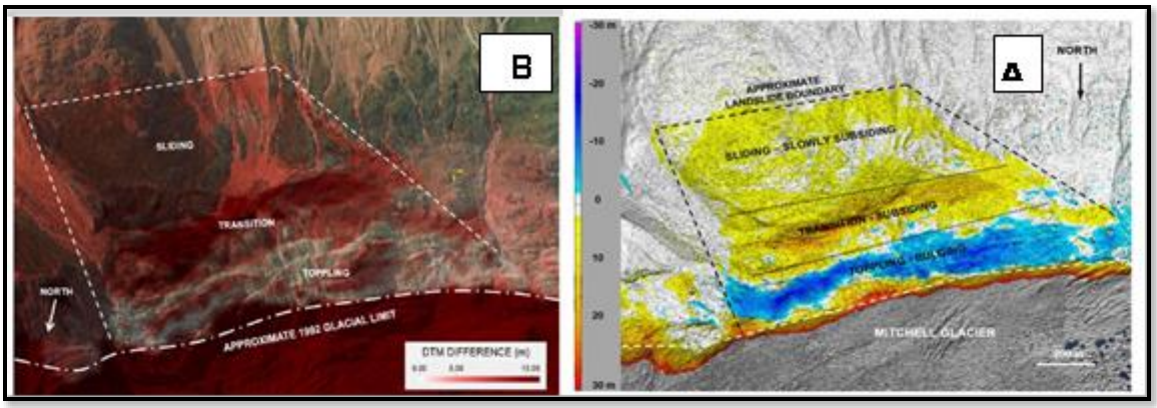

Figure 10. Comparison of point clouds for the years 1992 and 2010 using photogrammetric models. (a) An oblique view of a map generated from a Digital Terrain Model (DTM) created using 3DM, (b) showing the negative surface changes between 1992 and 2010 .

B– The study by Mazarakis et al. (2021), entitled *"Rockfall Analysis in the Kakia Skala Area, Greece"*, highlights that rockfalls pose a significant hazard to human activities and infrastructure. Consequently, analyzing rock masses from an engineering geomorphology perspective is critically important, particularly along transportation routes and in other geotechnical works. This research presents a rock mass classification and a limestone rockfall hazard rating system for one of the most important highways in Greece. The two most hazardous sites were selected as case studies, where the RockFall software was employed (Figure 11) to estimate the trajectories and kinetic characteristics of unstable rock blocks. The objective was to determine the most suitable engineering protection measures, with the correct dimensions and at the optimal locations, based on the kinetic energy of the falling rocks. To achieve this, a database was developed incorporating the engineering geomorphological characteristics of the slopes and the engineering geological properties of the rocks. The study concluded that limestone, steep slopes (Plate 2) resulting from numerous faults, and seismic activity are the primary causes of rockfalls in the area. Using RockFall modeling, the most appropriate rockfall protection system was identified as **GEOBRUGG RX-150** (Figure 12), which can absorb up to 1,500 kJ of energy—exceeding the maximum expected energy of potential rockfalls.

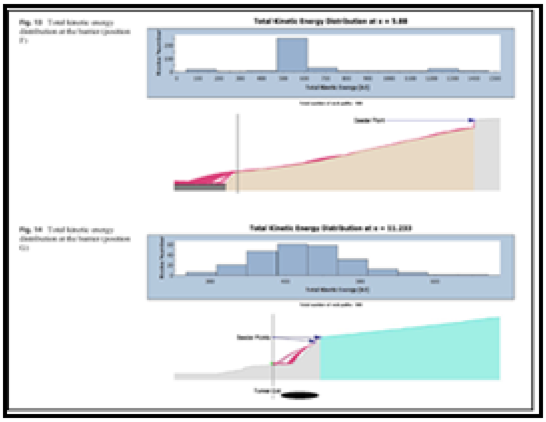

Figure 11. Rockfall Software Analysis of Rockfall Trajectories

Figure 12. GEOBRUGG RX-150 Protection System

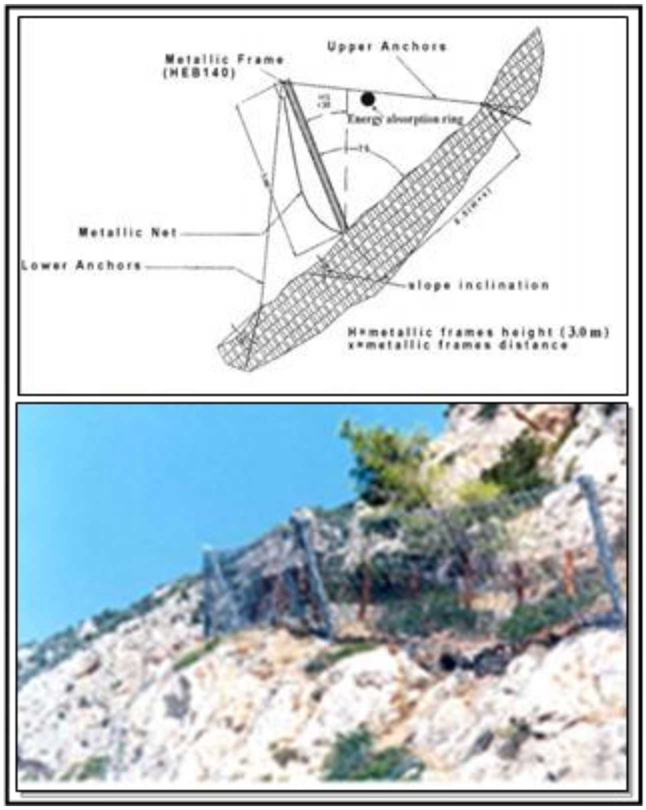

Plate 2. Fault at Kakia Skala, above the old regional road, 49.5 km west of Athens

C– The study by Conforti & Letto (2019), entitled *"An Integrated Approach to Assessing the Impact of Slope Instability on Infrastructure"*, focuses on an area located along the northern boundary of the Monte Poro Plateau, on the Tyrrhenian coast of Calabria (southern Italy). The area is characterized by weathered gneiss rocks, which have undergone significant weathering processes, resulting in widespread landslides. This research adopted an integrated approach to examine the relationships between the geological, geomorphological, and engineering environments and the landslides that occurred during road construction. The geomorphological analysis was carried out using a combination of aerial photographs, satellite imagery, and Digital Elevation Models (DEMs). Weathered gneiss rock mass classifications were applied to assess rock quality and to determine the potential stability conditions of slopes. The study also evaluated natural changes resulting from road construction and the occurrence of landslides after road works. A total of 32 landslide sites were identified prior to road construction, while 27 landslides were recorded after the road was built (Figures 13 and 14). Findings indicated that highly weathered rocks and clay deposits are more prone to landslides and are more severely affected by them, whereas rocks exhibiting varied degrees of weathering show a lower incidence of landslide occurrence. The research also concluded that road construction activities had a significant impact on the engineering geomorphological scenario, exacerbating landslide activity in an area already characterized by a high susceptibility to slope failure.

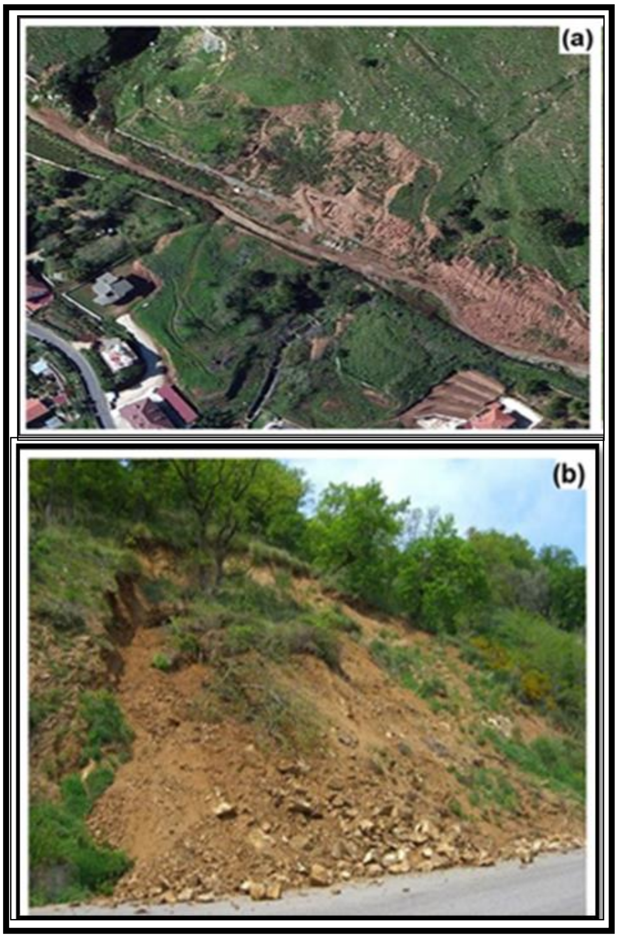

Figure 14. (A) Rotational slide along the road under construction
(B) Shallow landslides along the road under construction

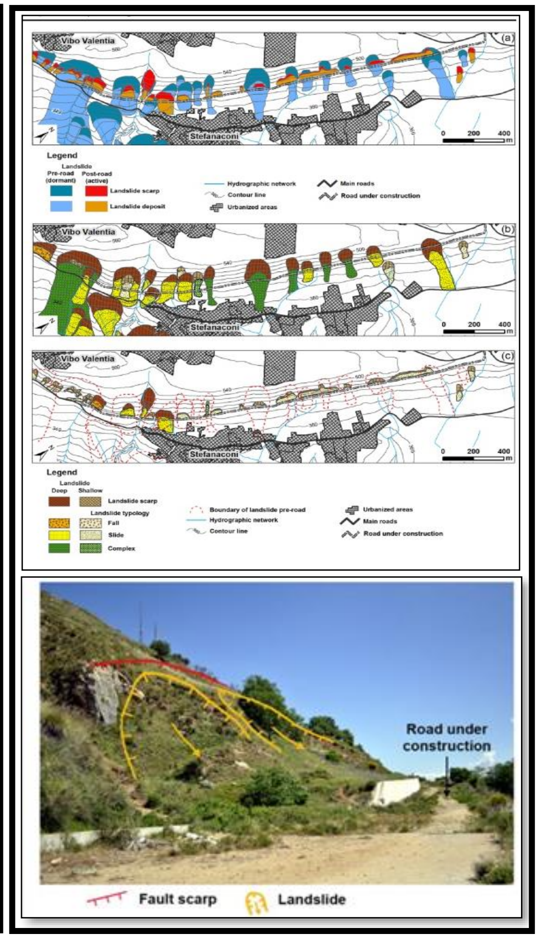

Figure 13. Distribution of landslides before the construction of the road, and active landslides after the road construction works

E– Study (Antronico et al., 2013) entitled *Slope movements induced by rainfall damage in an urban area: the case study of Catanzaro (Calabria, Southern Italy)* examines slope instability within the densely populated district of Ianò, located in the central–western sector of Calabria. The landslides that occurred in February 2010 resulted in extensive damage to the built environment and infrastructure, significantly heightening the risks faced by local residents. The investigation employed an integrated methodological framework combining detailed field surveys, remote image interpretation, rainfall data analysis, assessment of urban development dynamics, and systematic mapping of landslide-related damage (Figure 15). This comprehensive approach enabled the formulation of hypotheses regarding the underlying factors responsible for the reactivation of slope movements. The results revealed that the February 2010 landslides were predominantly reactivations of pre-existing landslide deposits, triggered by the cumulative effect of rainfall over a 15-day period, and further exacerbated by the widespread construction of road networks developed after the 1950s to connect newly established villages. In addition, unregulated urban expansion within an area inherently prone to high instability intensified the severity of the events, as numerous buildings were constructed either on or adjacent to pre-existing landslide slopes, while in other cases, structures were erected directly within landslide bodies, such as those observed in the small village of Scala.

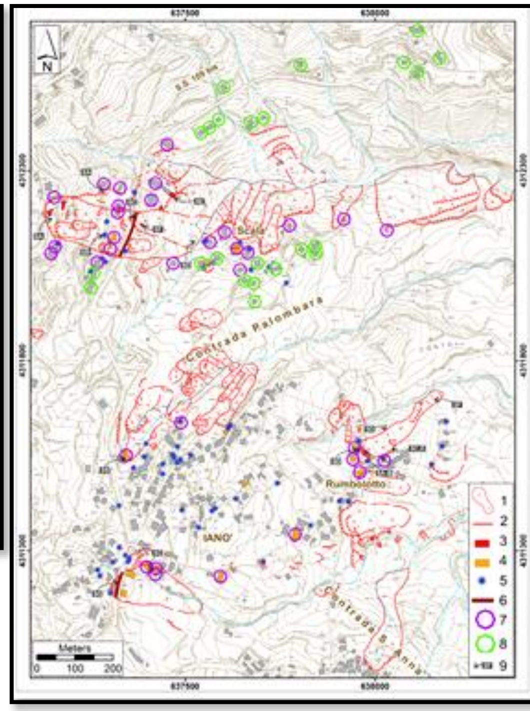

Figure 15. Map of the damage to buildings and roads after the February 2010 event in the village of Scala, with selected examples.

2– Applications of Engineering Geomorphology in the Study of Rivers and Wetlands:

A– Study (Bravard et al., 1999) entitled Principles of engineering geomorphology in river channel management, erosion, and bedload transport: examples from French rivers highlights how French rivers have, over centuries, fulfilled diverse social development needs such as navigation, hydropower generation, and agriculture. This was achieved through extensive engineering and geomorphological modifications of rivers, including flood control and fluvial erosion management. However, such interventions have produced adverse effects on the environment, natural resources, and human interests. In recent decades, growing public and administrative awareness of these issues has opened the way for new concepts and objectives in the field of river engineering geomorphology, particularly the pursuit of long-term sustainable management strategies. Since many of the challenges are directly or indirectly linked to changes in the geomorphological performance of river systems, the integration of a geomorphological approach into river engineering practices has become increasingly necessary. This shift is reflected in the themes and research trends addressed by fluvial engineering geomorphology in order to identify applicable solutions (Figure 16).Among these themes are: changes in river discharge, the impact of land reclamation on sediment supply and its subsequent reduction within river systems, the modification of sediment transport processes through the removal of artificial structures (such as dams, weirs, and bridges), and the influence of human interventions on river channels—such as straightening, narrowing, armoring, or constructing artificial banks—which have negatively affected channel morphology and navigation. Additionally, the geomorphological consequences of dam construction have emphasized the crucial role of engineering geomorphology in providing guidance and applied studies aimed not only at mitigating the harmful impacts of traditional management strategies, but also at promoting the sustainable restoration of river environments. Thus, engineering geomorphology emerges as a multidisciplinary approach to the comprehensive management of river systems.

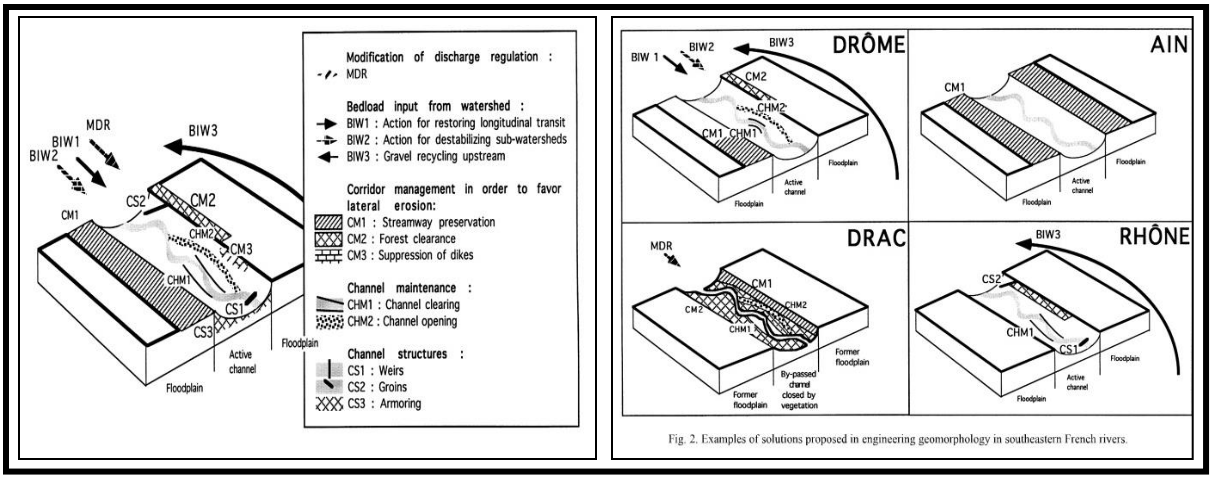

Figure 16. Examples of proposed solutions in engineering geomorphology for rivers in southeastern France.

B– Study (Can et al., 2021) entitled the effects of dam construction on river channel geomorphology examines the geomorphological impacts of dam building on river morphology, including changes in cross-sectional profiles and the overall transport of sediments on both annual and seasonal scales. The research focused on the Büyükkumla Dam—located in the southeastern part of the Sea of Marmara, approximately 10 km northwest of Bursa Province, along the Büyükkumla River, which flows from the dam's outlet channel into the Sea of Marmara—and its influence on channel morphology. To achieve this, the study analyzed channel cross-sections and the spatial distribution of erosion and deposition zones through field measurements. Topographic surveys were conducted every six months from the start of dam construction in 2013 until the completion of the dam body in 2018, covering the entire river channel, including its bed and banks. The river course was divided into three segments, and findings indicated that the middle reaches of the channel exhibited significant geomorphological changes in cross-sectional profiles throughout the study period, characterized by bed-level increases due to sediment deposition and decreases due to erosion (Figure 17). The study investigated the underlying causes of these changes, taking into account construction activities and meteorological conditions, and revealed a clear relationship between excavation works during dam construction and the geomorphological alterations within the river channel, which varied across different time periods. The study concludes by recommending the integration of advanced technologies such as LiDAR and laser scanning in future research, while emphasizing that monitoring the river channel several years prior to dam construction would provide a more accurate and effective basis for evaluation.

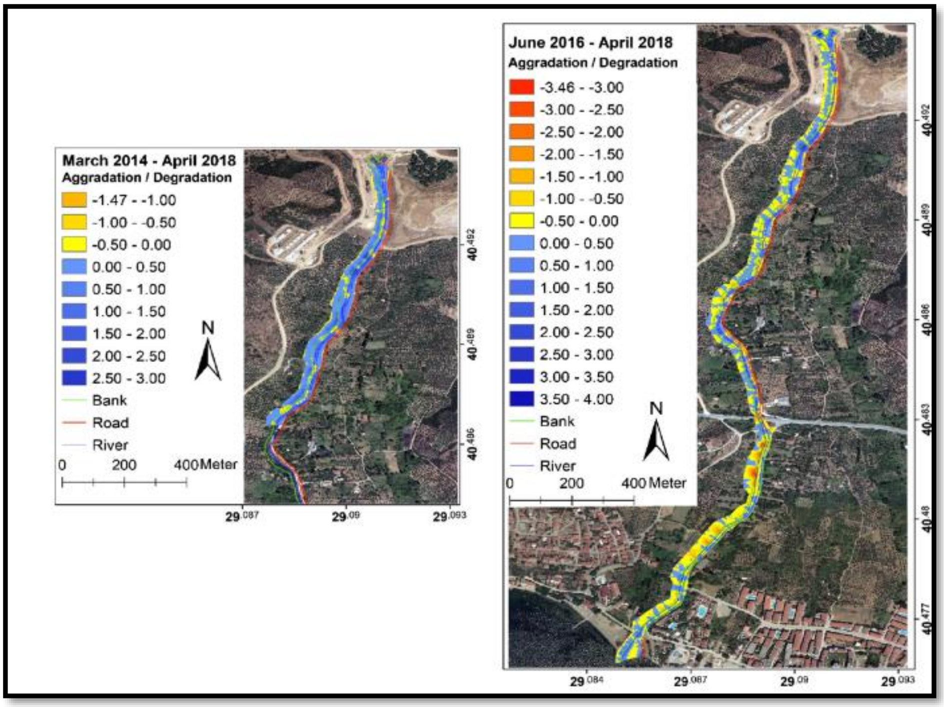

Figure 17. Spatial distribution of variations in topographic measurements during the periods (2014–2018) and (2016–2018).

3– Applications of Engineering Geomorphology in the Study of Coastal Areas: Study (Valero et al., 2017) entitled *Assessing human impacts on the coastal landforms of Gran Canaria Island (Canary Islands)* (Figure 18) investigates the geomorphological consequences of human activities on highly sensitive coastal environments. The coastal areas of the Canary Islands are particularly vulnerable to both natural and anthropogenic (social and economic) changes; therefore, the study aimed to analyze coastal conservation from a geomorphological perspective, taking into account the transformations brought about by urban and tourism development (Plate 3). The research was approached through an engineering geomorphology framework, which included detailed mapping of the island's coastal landforms (256 km in perimeter) and a comparative assessment of coastal geomorphology before urban and tourism development (late 19th century) and after, classifying landforms into four categories according to the degree of human impact: unchanged, modified, semi-destroyed, and extinct. The study relied on the integration of photographic and topographic sources within a Geographic Information System (GIS), complemented by field surveys in areas affected by engineering works, as well as historical geographic sources to reconstruct conditions prior to urban and tourism development. The results revealed that 43% of the coastal landforms had been affected by human interventions, with the most impacted being sedimentary landforms such as dunes, beaches, and wetlands, leading to a significant reduction in geomorphological diversity. The loss of coastal geomorphological diversity was estimated as a total or partial destruction of landforms amounting to –15.2% according to the Shannon Index, and rising to –32.1% when measured with an index proposed in this study.

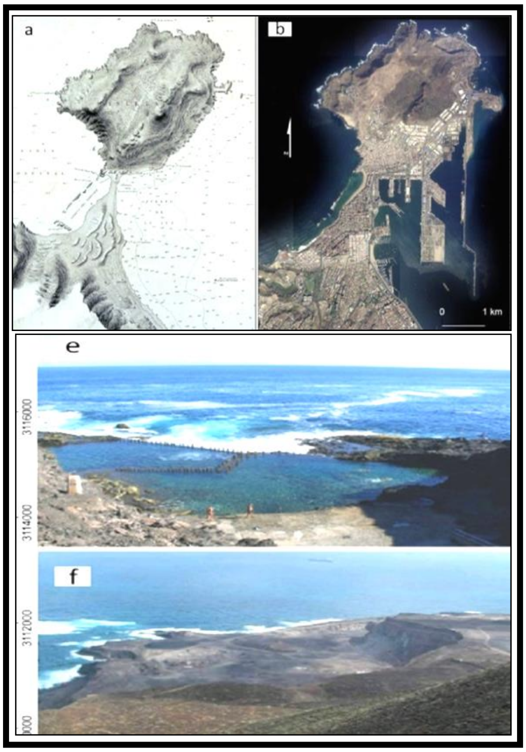

Plate 3. Examples of the consequences of urban and tourism development along the coast of Gran Canaria, illustrating the radical changes in coastal cliff dynamics and the complete destruction of some beaches.

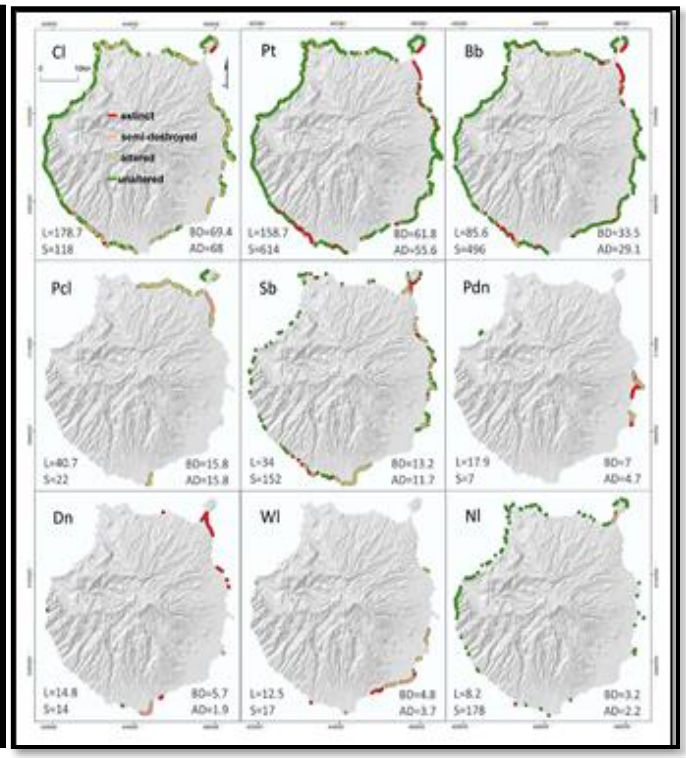

Figure 18. Distribution of coastal landforms around the island: CI – coastal cliffs, Pt – coastal platforms, Bb – rocky beaches, PcI – ancient coastal cliffs, Sb – sandy beaches, Pdn – ancient coastal dunes, Dn – coastal dunes, WI – coastal wetlands, NI – nearshore landforms.

4-Applications of Engineering Geomorphology in the Study of Economic Activities:

Study (Hearn, 2002)[(7)] entitled Engineering geomorphology for road design in unstable mountainous regions: lessons learned after 25 years in Nepal demonstrates that the application of engineering geomorphology within geotechnical studies during the design and construction phases has proven to be highly beneficial. In several cases, the lack of adequate geological or engineering geomorphological assessment resulted in recurrent problems that necessitated design modifications. Consequently, geomorphological evaluation must be considered an integral component of road construction and rehabilitation schemes in highly rugged terrains (Figure 19), as it assists in interpreting complex or uncertain ground conditions and in assessing natural hazards. The continuous evaluation provided by engineering geomorphology throughout the intended design life of engineering structures—and beyond—represents its principal function. To achieve this, it is essential to derive an integrated engineering assessment that combines short-term, static engineering geological maps with long-term, dynamic engineering geomorphological maps of the landscape, in addition to a comprehensive understanding of engineering design standards. The more dynamic natural processes become, and the greater the uncertainty regarding their formation and mechanisms of change, the stronger the need for specialized geomorphological assessment. Hence, accumulated expertise and the acquisition of

[7]) This study falls outside the survey period; however, it is considered one of the important contributions that clearly address the applications of engineering geomorphology, supported with examples from various regions where it is linked to economic activities, particularly road construction and design. Therefore, it was selected for inclusion.

geomorphological process data constitute the only means of reducing this uncertainty, which can be achieved solely through close observation, continuous monitoring, and the refinement of interpretive approaches.

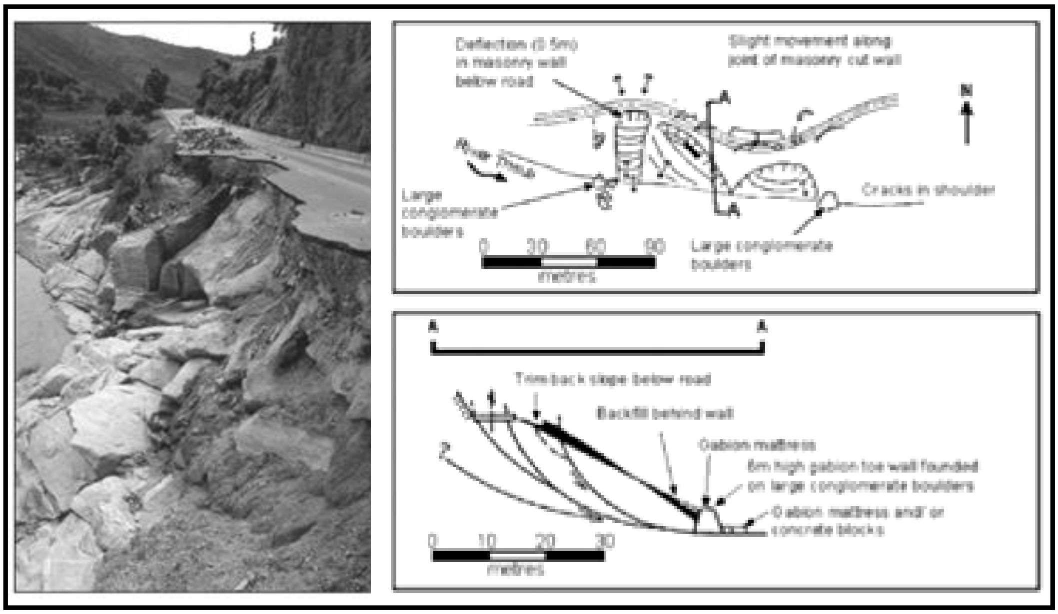

Figure 19. Development of a geomorphological map for rehabilitation along the Prithvi Highway after the 1993 flood, showing the effects of river erosion along the Naubise–Mugling road

Fifth: Recent Advances in the Techniques Applied in Engineering Geomorphology Studies (2012–2022):

The techniques adopted in engineering geomorphology research have exhibited substantial diversity, both within the scope of the selected journals and across the principal research domains. These techniques have been systematically classified into six categories of application, which have been examined as follows:

1- Numerical and Relative Distribution:

An analysis of Table 7 and Figure 20 reveals the following facts:

-The application of Geographic Information Systems (GIS) and Remote Sensing accounted for the largest share of engineering geomorphology research, ranking first with 118 studies, representing 48.8% of the total—nearly half of all engineering geomorphology studies employ this application. Within this category, the journal Geomorphology represented 31.4% of the total studies utilizing these techniques, followed by Natural Hazards at 14.4%, and Arabic journals at 12.7%. This predominance is to be expected, as geomorphological processes cannot be effectively interpreted, nor their impacts on engineering structures assessed, nor the most appropriate protection measures identified, without the creation and analysis of a comprehensive database using GIS and Remote Sensing.

- Studies that combined multiple techniques or spatial analysis approaches, alongside theoretical investigations, occupied the second rank with a total of 69 studies, accounting for 28.5% of all research in engineering geomorphology. Collectively, the journals Geomorphology and Earth Surface Processes accounted for 66.7% of the total studies employing this approach.

- The use of mathematical and hydrological modeling in engineering geomorphology ranked third, encompassing 44 studies and accounting for 18.2% of the total research output. Among these, the *Geomorphology* journal published the largest share with 15 studies, followed by the *Landslides* journal with 8 studies.

- By contrast, the adoption of other advanced applications—such as LiDAR data, laser scanning, and unmanned aerial vehicles (UAVs)—was markedly limited, representing only 4.5% of the total. Although this percentage is relatively modest, numerous studies have employed these techniques in conjunction with Geographic Information Systems (GIS) or remote sensing to enhance analytical capabilities.

-Research published in Arabic sources was predominantly confined to three applications: GIS and remote sensing (9.9%), modeling applications (0.4%), and other applications (0.4%). This underscores the significant gap between Arabic and international research, both in terms of research volume and the level of technological advancement applied in engineering geomorphology studies.

Table 7. The Numerical and Relative Distribution of Applications and Techniques Used in Engineering Geomorphology Studies during the Period (2012–2022)

Foreign and Arabic Journals, and Academic Theses	Applications and Techniques Used in Engineering Geomorphology Studies						Total
	Geographic Information Systems (GIS) and Remote Sensing	High-Resolution Airborne LiDAR Data	Mathematical and Hydrological Models	Laser Scanning System	Unmanned Aerial Vehicles (UAVs)	Others	
Geomorphology	**37**	**1**	**15**	**1**	**2**	**34**	**90**
Earth Surface Processes	**8**	**1**	**6**	**2**	**2**	**12**	**31**
Physical Geography	**2**	**0**	**1**	0	0	**1**	**4**
Landslides	**13**	**0**	**8**	0	0	**6**	**27**
Progress in Physical Geography	**1**	**0**	**1**	0	0	**1**	**3**
Natural Hazards and Earth Sciences	**17**	**0**	**6**	0	0	**3**	**26**
Applied Geography	**3**	**0**		0	0	**1**	**4**
Arabian Journal of Geosciences	**7**	**1**	**3**	**1**	0	**4**	**16**
Engineering Geology	**2**	0	**1**	0	0	**0**	**3**
Engineering Geology Bulletin	**2**	0	**0**	0	0	**2**	**4**
Quarterly Journal of Engineering Geology	**2**	0	**2**	0	0	**4**	**8**
Arabic Journals	**15**	0	**1**	0	0	**1**	**17**
Academic Theses	**9**	0	**0**	0	0	**0**	**9**
Total	**118**	**3**	**44**	**4**	**4**	**69**	**242**

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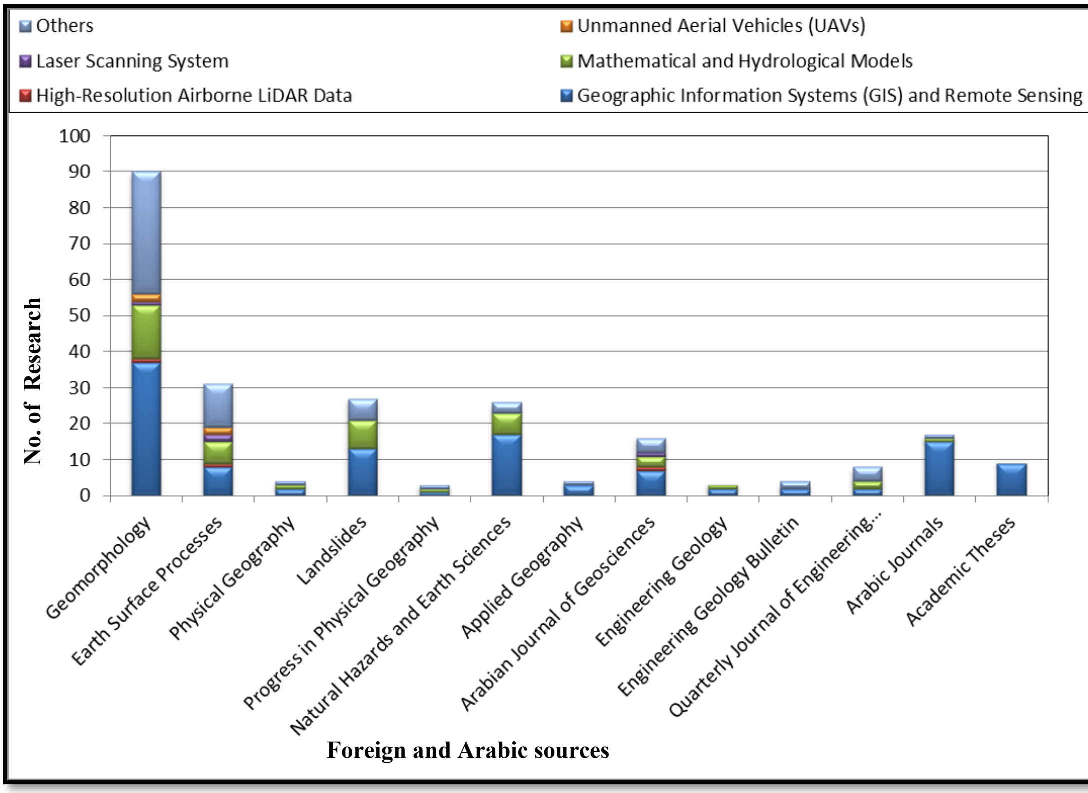


Prepared by the researcher based on Table 7.

Figure 20. The numerical distribution of applications and techniques used in engineering geomorphology studies during the period (2012–2022)

2-The Development of Applications and Techniques Used in Engineering Geomorphology Studies in Foreign and Arabic Journals during the Period (2012–2022):

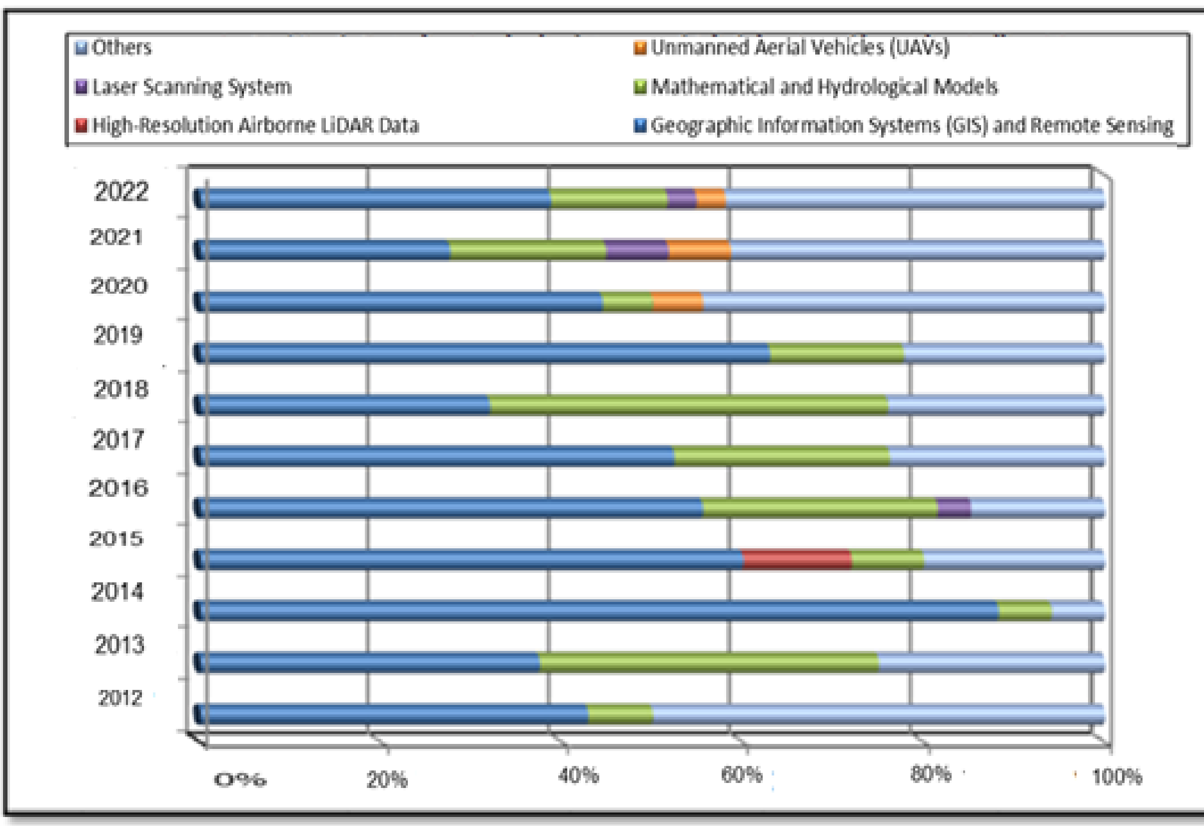
It is evident from the development of applications and techniques employed in engineering geomorphology studies, as presented in Table 8 and Figure 21, the following:

- The use of Geographic Information Systems (GIS) and Remote Sensing applications consistently ranked first in engineering geomorphology studies throughout the study period, although their frequency varied from year to year. The year 2013 recorded the lowest number of studies applying this technique, with only three studies (2.5%), whereas 2019 witnessed the highest, with seventeen studies (14.4%).
- The application of mathematical and hydrological models showed a similar pattern of prominence during the entire period (2012–2022). The year 2018, however, marked the peak in the use of this technique, with eleven studies (25%).
- Studies that relied on employing multiple techniques in engineering geomorphology research showed a clear upward trend from 2012 to 2022, increasing from seven studies in 2012 to thirteen studies in 2022—rising from 10.1% to 18.8%.
- By contrast, the number of studies that utilized LiDAR, laser scanning, and unmanned aerial vehicles (UAVs) remained limited, amounting to a combined total of eleven studies (4.5%). Nevertheless, the specific years of their application varied: three studies in 2015 focused on LiDAR, one study in 2016 applied laser scanning, and a single study in 2020 employed UAV technology.

Table 8. The development of applications and techniques used in engineering geomorphology studies in foreign and Arabic journals during the period (2012–2022)

Year	Geographic Information Systems (GIS) and Remote Sensing	High-Resolution Airborne LiDAR Data	Mathematical and Hydrological Models	Laser Scanning System	Use of Unmanned Aerial Vehicles (UAVs)	Others	Total
2012	6	0	1	0	0	7	14
2013	3	0	3	0	0	2	8
2014	15	0	1	0	0	1	17
2015	15	3	2	0	0	5	25
2016	15	0	7	1	0	4	27
2017	11	0	5	0	0	5	21
2018	8	0	11	0	0	6	25
2019	17	0	4	0	0	6	27
2020	8	0	1	0	1	8	18
2021	8	0	5	2	2	12	29
2022	12	0	4	1	1	13	31
Total	118	3	44	4	4	69	242

Prepared by the researcher based on the survey of studies in foreign and Arabic sources during the period (2012–2022)



Prepared by the researcher based on Table 8.

Figure 21. The development of applications and techniques used in engineering geomorphology studies in foreign and Arabic journals during the period (2012–2022)

3- Examples of Foreign and Arabic Studies According to the Techniques and Applications Used:

A. Laser Scanning System:

The study by *Ibisate et al. (2016)*, entitled *"Geomorphic Monitoring and Dam Removal: A Case Study of the Oromia and Litzaran River Dams (Spain),"* aimed to demonstrate that dam removal is among the most effective methods for restoring river channels. However, it requires extensive geomorphological and engineering monitoring. To achieve this, a number of techniques were employed to identify geomorphological indicators of channel adjustment following dam removal. This was accomplished through cross-sectional channel analysis and topographic surveying using a laser scanner with a resolution of 10 cm. In addition, a high-resolution Digital Terrain Model (DTM) with 5 cm accuracy was applied to obtain detailed information on channel changes, including riverbanks and in-channel barriers (Plate 4).

Plate 4. (A) Detailed photograph of barrier (5)
(B) The same image using the laser scanner

B. Geographic Information Systems (GIS) and Remote Sensing:

The study by Bordoloil et al. (2020), entitled *"Assessment of Riverbank Retreat and Its Potential Erosion Using Spatial Analysis: A Case Study of the Subansiri River, Assam, India,"* employed an integrated approach combining Geographic Information Systems (GIS) and Remote Sensing. This was achieved through spatial analysis using a model known as Graph, based on Landsat satellite imagery, with the aim of mapping the morphological changes of the river channel. By applying this model, the study estimated riverbank erosion rates and identified appropriate protective measures for effective river management.

C. Unmanned Aerial Vehicles (UAVs):

The study by Nguyen et al. (2020), entitled *"Rainfall-Induced Landslides on the New Highway: A Case Study in Vietnam,"* investigated the factors contributing to a landslide that occurred in 2018 along the Halong–Vandon Highway, which sustained significant damage. The research relied on aerial imagery captured by an unmanned aerial vehicle (UAV) to conduct engineering geomorphological mapping. The analysis enabled the precise identification of the causes and influencing factors behind the landslide, which, in turn, supported the development of effective solutions for slope stabilization.

D. High-Resolution Airborne LiDAR Data:

The study by Yusof et al. (2015), entitled *"Landslide Hazard Assessment along the Jelapang Highway, Malaysia, Using High-Resolution Airborne LiDAR Data,"* aimed to spatially predict landslide-prone areas along the Jelapang Highway in Malaysia. To achieve this, two statistical models were employed: **Logistic Regression (LR)** and **Evidence Belief Function (EBF)**—both widely used multivariate statistical approaches for evaluating landslide susceptibility. The study produced landslide susceptibility maps and identified areas at high risk of failure. The results demonstrated that the LR model outperformed the EBF model, providing more accurate and reliable predictions of landslide-prone zones. The research concluded by recommending the application of the LR model in generating landslide susceptibility maps, as these maps can support planners and decision-makers in mitigating and preventing future landslide hazards.

E. Mathematical and Hydrological Models:

The study by Abdul Karim (2021), entitled *"Flash Flood Hazards along the Railway Track: The Wadi Bayir Basin Affecting the Route of the North Train South of Al-Qurayyat City, Saudi Arabia – A Case Study,"* assessed flood risks using two-dimensional spatio-temporal modeling integrated with Remote Sensing and Geographic Information Systems (GIS). The hydrological model HEC-HMS was applied to generate flood hydrographs for different catchment basins and to estimate floodwater volumes and flow rates based on the SCS Unit Hydrograph method. Rainfall depth was also analyzed and estimated for various return periods. Furthermore, the hydraulic model HEC-RAS (Hydrologic Engineering Center – River Analysis System) was utilized to perform two-dimensional spatio-temporal simulations, enabling the calculation of floodwater velocity, depth, and extent, as well as the identification of areas vulnerable to inundation.

F. Others (Use of Multiple Techniques):

The study by Biswas & Banerjee (2018), entitled *"Bridge Construction and Channel Morphology: A Comprehensive Study of Flow Behavior and Sediment Load Variations in the Shill River, India,"* examined the hydrological alterations caused by the construction of a bridge in 1970. The bridge led to modifications in river behavior, including bank erosion and flooding, which in turn affected agricultural lands on both sides of the river as well as human settlements. To investigate these changes, hydraulic modeling using the HEC-RAS software (Figure 22) was employed to illustrate channel modifications following bridge construction and to simulate a hypothetical scenario of the river's condition without bridges. The study also incorporated multiple datasets, including SRTM–ASTER DEM (90 m resolution), satellite imagery from LISS III and LISS IV, in addition to the use of Surfer 11 and ArcGIS 10.2.2 software.

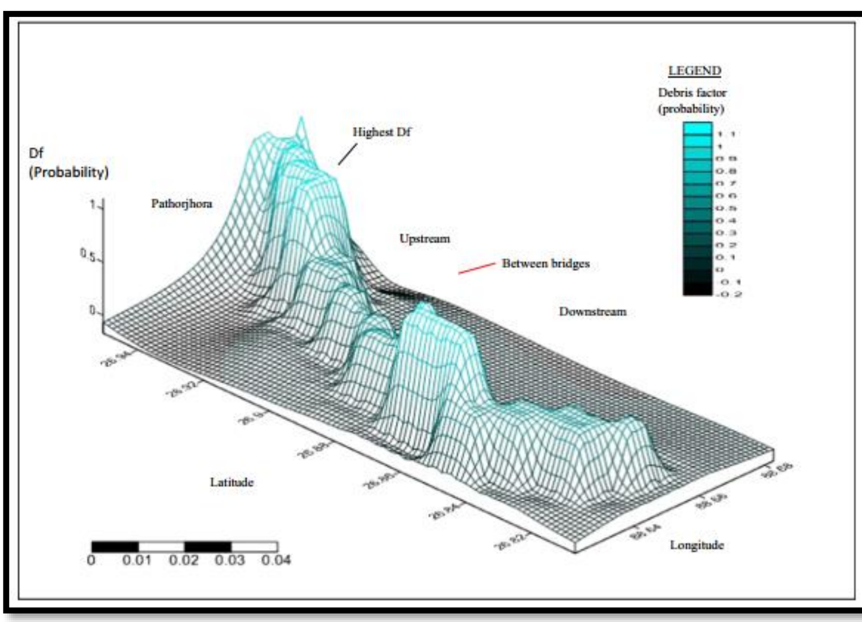


Figure 22. Graph showing massive sediment deposits near the bridge, both upstream and downstream

Fifth – Conclusion:

The study of recent trends in engineering geomorphology research has revealed a set of findings and recommendations that can be summarized as follows:

Findings:

1. Arab studies addressing topics in engineering geomorphology were found to be limited in scope (26 studies), in contrast to foreign studies, which were characterized by diversity and richness (216 studies) in their treatment of research themes, covering most aspects of the field.
2. During the 1960s and 1970s, engineering geomorphology research was largely confined to a single theme—landslide studies. These works focused on the historical development of landslides, their causative factors, attempts to link them to past climatic conditions, and the search for mitigation strategies. However, over the past decade, research output has expanded significantly to encompass additional thematic directions.
3. Recent trends in engineering geomorphology research, as reflected in foreign sources, have concentrated primarily on two fields: fluvial and wetland engineering geomorphology, and slope engineering geomorphology. In contrast, coastal engineering geomorphology emerged as the dominant research direction in Arab sources.
4. The development of engineering geomorphology research has been marked by fluctuation—not only in the overall number of studies but also across the thematic domains. Despite this variation, research output has shown a clear upward trajectory, particularly during the period (2019–2022).
5. The geographical distribution of studies on engineering geomorphology in both foreign and Arab sources across continents and countries displayed significant variation. Research spanned 49 countries, with Asia accounting for 32.7% of the total studies published in foreign sources, most of which were concentrated in China. Europe ranked second with 27.7%, where Italy contributed the largest number of studies. Africa ranked fourth with 9.2%, with Egypt leading the continent in terms of research output.
6. Recent research trends in engineering geomorphology have varied across continents and countries. In Asia, the dominant research orientation focused on fluvial processes and their impact on engineering structures. In Europe, the prevailing focus was on slope studies and landslide analysis. North American research trends resembled those of Asia, emphasizing fluvial studies, while Arab studies tended to concentrate on coastal geomorphology.
7. The application of Geographic Information Systems (GIS) and Remote Sensing accounted for the largest share of engineering geomorphology studies, ranking first with 118 studies (48.8%), which represents nearly half of the total research output in this field. Studies that combined multiple techniques or spatial analysis methods alongside theoretical approaches ranked second, with 69 studies (28.5% of the total).
8. Compared to foreign sources, Arab research was notably limited in the range of techniques applied in engineering geomorphology studies. It was largely confined to three applications: GIS and Remote Sensing (9.9%), modeling (0.4%), and integrated modeling with Remote Sensing (0.4%)—all of which represent very low proportions.
9. The use of certain techniques, such as laser scanning, UAVs, and high-resolution LiDAR, appeared to be relatively limited in foreign studies. However, this should not be interpreted as an indicator of their scarcity. Rather, a careful review of the literature revealed that these techniques were often employed in combination with others, thereby increasing their frequency under the category of "Others" rather than as standalone methods. This reflects the growing integration of techniques to produce more accurate and generalizable results.
10. Engineering geomorphology research in Arab sources has not applied any of the three techniques—UAVs, LiDAR, or laser scanning—whether individually or in

combination with other methods. This underscores the clear lag of Arab research compared to foreign contributions.

11. The analysis of the development of techniques used in engineering geomorphology studies revealed notable variation from year to year. Nevertheless, some techniques have shown an upward trend in recent years, particularly within the category of "Others," where multiple techniques are employed in combination. This reflects the contemporary trend toward methodological integration to achieve more robust and reliable findings.

Recommendations:

1. Research should be directed toward the adoption of modern techniques and their potential applications in addressing the needs of engineering geomorphology studies. This would enable the production of more reliable data, enhance competitiveness with engineering geology and civil engineering, and affirm the rightful position of engineering geomorphology within this field—particularly in Arab sources, where such approaches remain largely absent.
2. Greater attention should be given to expanding research in specific subfields that are currently underrepresented. Two key areas require further investigation: karst engineering geomorphology and arid-land engineering geomorphology. This applies to both foreign and Arab sources.
3. Stronger collaboration is required between academic institutions (departments of geography and geology in universities and research centers) and professional/consulting bodies (civil engineering authorities). Such cooperation should provide researchers with comprehensive knowledge of engineering geomorphology, in addition to offering proper training and field experience to develop their technical skills and monitoring capabilities.
4. Researchers in universities should be encouraged to work within multidisciplinary research teams—an approach that is well established in foreign studies but is almost absent in Arab research.
5. Graduate students should be guided toward engaging with advanced modern techniques, particularly those applied in understanding and interpreting geomorphological processes. These include photogrammetry based on surveying instruments, and advanced mathematical models such as **GeoRock**, **Rockfall**, and various statistical models adopted in the present study, rather than relying exclusively on the GIS environment.

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