Review

Landslides in the Himalayas: A Comprehensive Review of Hazards, Impacts, and Adaptive Strategies

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Received: 17 December 2024; Accepted: 17 January 2025; Available online: 5 February 2025

ABSTRACT: The Himalayas, known as the 'Third Pole', are facing an escalating crisis due to landslides driven by climate change and human activity. The settlements in the Himalayas are increasingly vulnerable due to a surging prevalence of landslides. This systematic review investigates the repercussions of landslide hazards on the inhabitants of the Himalayan Arc and explores the causes and adaptive strategies focusing on the period from 2002 to 2022. Data dealing with the impact of landslides were systematically extracted from Scopus, Web of Science, Pascal & Francis, Science Direct, and Google Scholar databases. The review adhered to the prescribed guidelines of reporting standards for systematic evidence systems (ROSES). The frequency and severity of landslides in the Himalayas are notably high, potentially exceeding those observed in other global regions, due to a combination of specific geological, climatic, and human-induced factors. Thematic categorization identifies that the Himalayan communities confront a multifaceted challenge involving social, natural, economic, human, and physical losses induced by landslides. However, they lack adaptive capacity. The origins of these landslides are diverse, emanating from natural forces, geological phenomena, and human activities within the Himalayas. The review contributes to the understanding of the profound impact that landslides inflict upon the Himalayan region. By consolidating data from diverse databases, the study illuminates the urgent need for comprehensive strategies to bolster resilience and mitigate the escalating threats posed by landslides in this vulnerable geographic expanse.

Keywords: Disaster; Landslide; Himalayas; Impact; Adaptation; Systematic review

1. Introduction

Landslides are the 7th deadliest natural hazard in the world, accounting for 17% of all reported natural hazards [1]. The trend of landslides is said to be increased in the future due to increasing urbanization, deforestation, and climate change [2–4]. Asia is the continent with the highest risk of landslides, occurring mainly along the Himalayan arc [1,5]. As part of the slope failure phenomenon, landslides are, regularly occurring in South Asia [6]. According to data from EM-DAT depicted in Figure 1, data gathered between 1982 and 2022, Asia has been responsible for 58% of all landslides and 41% of all disasters [7]. In the Asian region, Southern Asia is most prone to landslides. It accounts for 34% of the continent's overall landslides. The Himalayan mountain range accounts for 89% of Southern Asia's landslides.

The Himalayas are the most affected area in terms of climate change, also known as the "third pole" [8]. The glaciers in the Himalayas are the largest outside the Polar Regions. The region is vulnerable to the most devastating natural disasters, causing huge loss of life, damage to property, and degradation of natural resources annually [9–11]. 1.9 billion people live in ten major river regions that rely on water from the melting glaciers and snow in the Himalayas [12]. Due to an increase in the population, unscientific settlements on slopes or vulnerable areas in a mountain, landslides and their impacts have been increasing in the past few decades [13]. It has a significant impact on settlements, agricultural land, transportation, communications, electricity supply, and other infrastructure [14–18]. The Himalayas are among the youngest mountain ranges, formed by the collision of the Indian and Eurasian plates, leading to highly fractured and unstable geological formations. Furthermore, extreme monsoonal precipitation saturates slopes in the Himalayas, triggering frequent landslides [19]. Moreover, the Himalayas are considered prone to earthquakes of high

https://doi.org/10.70322/rrd.2025.10002

magnitude [20], leading to a higher number of landslides. In the past, the Himalayan region has suffered numerous deadly earthquakes, including the Shillong earthquake of 8.1 magnitudes in 1897 [20,21], the Kangra earthquake of 7.8 magnitudes in 2005 [22], the Bihar-Nepal earthquake of 8.2 magnitudes in 1934 [21,23,24], the Assam earthquake of 8.6 magnitudes in 1950 magnitude [25], and the Gorkha earthquake of 7.8 magnitudes in 2015 [26,27]. As a result of earthquakes, landslides frequently occur in the Himalayan mountain region [28]. These disasters have tremendous effects on people, sometimes causing difficulties for government to cope with. The adaptive capacity of the government depends on how the financial, social, and political strength of the government exists. In the Wenchuan earthquake of 2008, people were shifted to the safe places at the expenses of US$ 147 billion [29] whereas the country's government failed in the 2005 Kashmir earthquake, Pakistan due to the unwillingness of locals to let refugees resettle in Balakot even after 15 years [30,31].

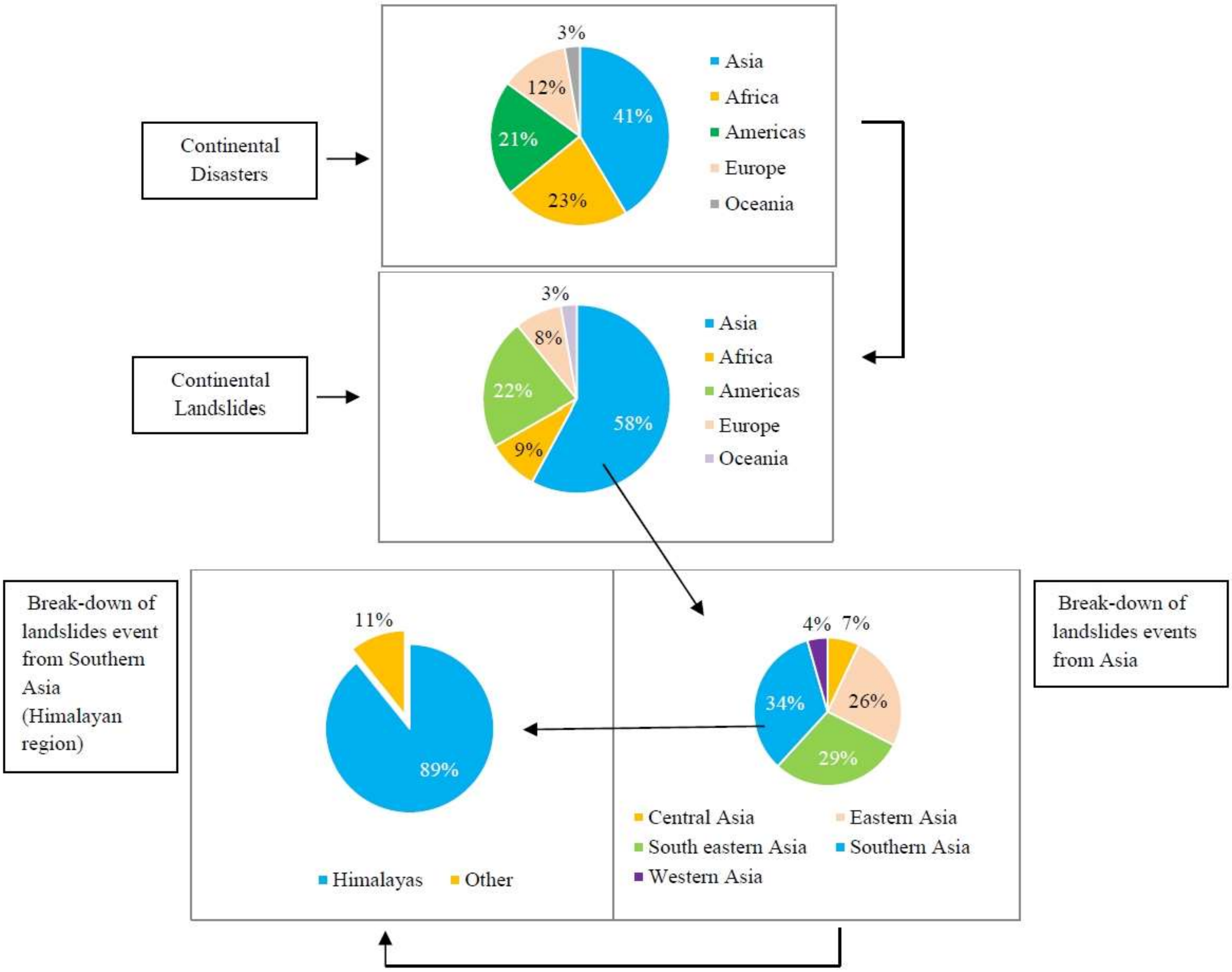


Figure 1. Continental-wise disaster and landslide data of the world.

Natural hazards, their causes, and their consequences have gained a wide range of attention from researchers around the world. Several global and local studies have incorporated the impacts of various hazards into their studies. There are various studies conducted on the impact of landslides in China [32], Germany [33], Malawi [34], Pakistan [35], Kenya [36], Sri Lanka [37], Nepal [38] and in Uganda [39]. Similarly, many studies have been conducted on the impact of landslides and the causes and trends of landslides in some parts of the Himalayan region [40,41]. However, there is a dearth of work that could represent the overall Himalayan region, particularly in terms of the impact of natural hazards on livelihood capital, the causes of landslides, and adaptive strategies to cope with impacts; this systematic review aims to fill that gap. The contribution of this study is to provide an overview of the impacts of landslides on the Himalayan region as discussed in the prior literature, analyzing the causes and raising awareness about the challenges of landslides in this region. It covers indirect losses due to landslides and psychological effects as well. This paper also highlights the importance of proactive measures and adaptive capacity to mitigate these risks and promote sustainability. In spite of the fact that the paper does not present any novel findings, it provides the reader with a panoramic view of landslide impacts on the Himalayas, which are among the most vulnerable areas for landslides. The first section of this review presents an introduction to the study. The second section explains materials and methods and then the results of the study. Finally, we analyze the discussion and give a conclusion.

2. Methodology

The study is focused on the impact of landslides in the Himalayan region, the causes of landslides, and adaptive strategies to cope with them. The main question for the study is, "What are the impacts of landslides in the Himalayas?". Other analyses have been conducted afterward, such as the geography of the Himalayas, changing climate, meteorology, and the occurrence of earthquakes, precipitation, and other natural phenomena. Landslides and their consequences in the Himalayas are a major phenomenon to be studied. Furthermore, marginalized and poor people are generally exposed with respect to landslides and are expected to be supported by the government [42]. Hence, we also focus on how to build the adaptive capacity of people living in the Himalayas.

The Himalayas are believed to have been formed through the collision between the Indian and Eurasian plates that started in the Paleogene era as a tectonically active young geological formation [43]. The Himalayan Mountain ranges are among the highest fourteen peaks in the world, including the highest peak Mt. Everest. The Himalayas extend 2400 km from east to west and 240 to 330 km wide from south to north [43]. The Eastern Himalayas cover 650 km from the Tsangpo-Brahmaputra Valley on the east to the Arun River Gorge on the west. The central Himalayas are expanded to the Sutlej River Gorge on the west from the Arun River, about 1200 km. Similarly, the western Himalayas have stretched about 550 km from the Sutlej River Gorge to the Indus Gorge, the Kashmir region, on the west [44]. The Indo-Gangetic Plains borders it on the south, the Tibetan Plateau on the north, and the Karakorum and Hindu Kush Mountains on the northwest. The region is divided into four sections based on thrust systems: Tethys Himalaya, Great Himalaya, Lesser Himalaya, and Outer Himalayas. A total of 750 million people live within the watershed of the Himalayan Rivers and 600 million people live in the Himalayas, including 53 million Indians. Three of the world's main rivers originate near the Himalayas, namely the Indus, the Ganges, and the Tsangpo-Brahmaputra [45].

The map of the study area is depicted in Figure 2.

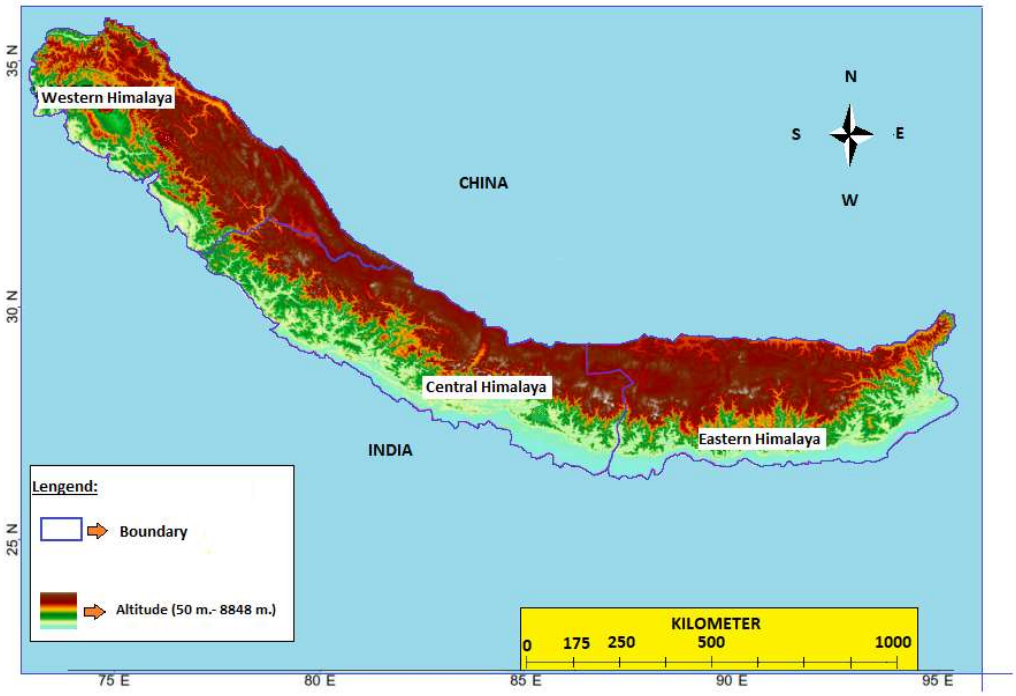


Figure 2. The location map of the study area.

The results of this study have been reported from the systematic review according to the Reporting Standards for Systematic Evidence Syntheses (ROSES). This review procedure is known as an effective tool for Environmental Research [46]. In the search string, key and associated words were searched using the Boolean operator (OR, AND), field code function, truncation and phrase search (Table 1).

Table 1. Search string and parameter for data search.

Data Base	Search String and Parameters
Web of Science	1. Impact (Topic) and Landslide (All Fields) and Himalaya Region (All Fields) 2. Refine by: Geochemistry, Geophysics & Geology, Climate change, Soil Science, Forestry, Environmental Science 3. Country: India, Nepal, Bangladesh, China 4. Year: 2002–2022
SCOPUS	TITLE-ABS-KEY (Impact* AND of AND landslide*) AND TITLE-ABS-KEY (Himalaya* AND region) AND (LIMIT-TO (OA, "all")) AND (LIMIT-TO (SUBJAREA, "EART") OR LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "AGRI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (AFFILCOUNTRY, "India") OR LIMIT-TO (AFFILCOUNTRY, "Nepal") OR LIMIT-TO (AFFILCOUNTRY, "China") OR LIMIT-TO (AFFILCOUNTRY, "Bangladesh") OR LIMIT-TO (AFFILCOUNTRY, "Pakistan")) Year: 2002–2022
Pascal & Francis	1. (Impact* OR Effect*) AND (Landslide* OR Mudslide* OR Rockslide* OR Earth fall* OR Snow slide* OR Avalanche) AND (Himalaya*) 2. Discipline (Document): Earth sciences, Pollution, Energy 3. Limiting to territory: India, China, Nepal, Pakistan, Bangladesh 4. Year: 2002–2014
Science Direct	1. Impact of Landslide in Himalaya Region 2. Access type: Open access 3. Discipline (Document): Environmental Science, Social Sciences 4. Type: Article 5. Year: 2002–2022
Google Scholar	1. Impact of landslide in the Himalayas 2. Limiting to territory: Bangladesh, Bhutan, Bangladesh, India, Nepal, China, Pakistan, Afghanistan 3. Custom range: 2020–2022 4. Sort by: Review article

As the most comprehensive databases of academic papers, Web of Science, Scopus, and Google Scholar are used to conduct a systematic research process [47–49]. The reviewer also used Science Direct and Pascal & Francis search engines for this systematic review. These search engines are particularly useful for finding relevant evidence as they contain large scholarly literature databases. Boolean operator (or, and) is used in search string for keywords to avoid unnecessary repetition. We conducted the screening with a core concern about the impact of landslides on Himalayan residents and other indirect implications of landslides. The inclusion/exclusion strategy was established based on subject area, type of document, open access, the publication year of the article, territory, and language. This review included empirical peer-reviewed studies published between 2002 and 2022 in English. A total of 26,329 studies were identified through electronic databases. Articles from 2021 and 2022 were searched in Google Scholar, considering the most recent articles. We could only review Pascal & Francis's articles from 2002 to 2014 because after 2014, the articles were no longer available in the search engine. This was based on subject, academic year, document type, publication title, open access, territory, and language. After inclusion and exclusion criteria, 216 articles were selected.

Other texts like books, thesis, review articles and duplicate articles from the full-text proficiency test are eliminated, resulting in 186 eligible articles for review. The titles of the articles were matched and verified with the review's objective. Next, 56 articles were removed after title screening and 77 articles after abstract screening, yielding 53 articles for full-text reading. Each publication's abstract was carefully read to ensure that the research objective was relevant to the study before the article was deemed eligible. After reading the full paper, 30 unmatched articles were again reduced to 23 articles for final analysis and 2 relevant articles from external sources were added. Finally, 25 articles were selected for critical appraisal.

For quality appraisal, two experts were asked to provide their opinions on the articles to confirm the quality of the selected literature [50,51]. As per the export suggestions, we identified 24 articles for the final review. Eighteen (18) articles were classified as high quality, six (6) as moderate, and one (1) as low quality, which was excluded from the literature analysis. The final reviewed paper is 24. The systematic search and processing strategy has been depicted in the flowchart (Figure 3).

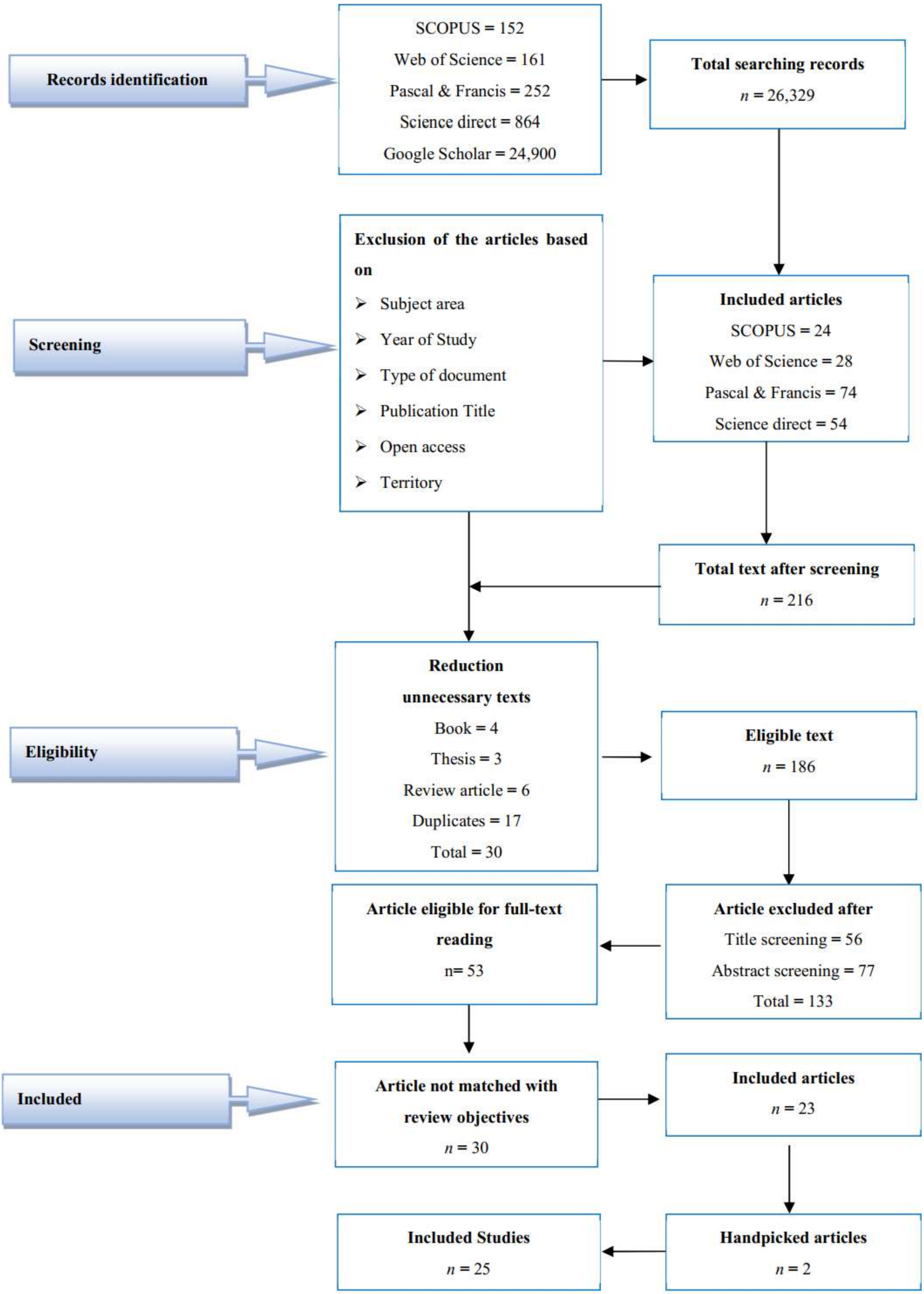


Figure 3. Systematic search and processing strategy.

To analyze the collected data, a well-recognized technique, the thematic integrative review methodology, was used [52,53]. Selected articles were classified into three themes: impacts of landslides, causes of landslides, and adaptive measures for landslide hazards. The impact of landslide hazards is based on the livelihood framework adopted by the Department for International Development (DFID). The causes of landslides in the Himalayas are divided into three sub-themes: Natural (climate-induced), Geology, and Anthropogenic causes. In addition, pro-active and reactive landslide mitigation measures are analyzed in the Himalayas.

3. Results

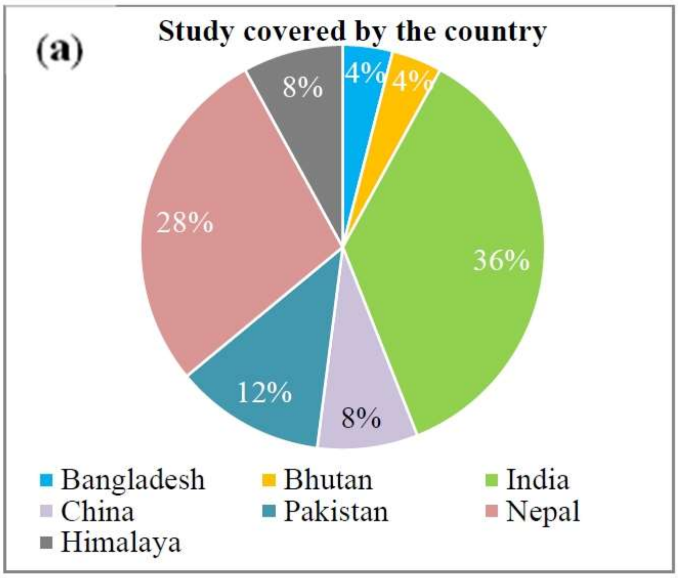
The review includes applied methods in the selected studies, spatial coverage in the study, temporal coverage of the study, and thematic categorization and analyses. The review focuses on the Himalayan zone, where the area is prone to landslides. In the period 2002–2022, peer-reviewed publications are covered. The details of the characteristics of the study are presented in Table 2.

Table 2. Details of the selected articles.

Type of Study	Publication Year	Country	Study Method	Reference	Quality
Landslide Lake Out Burst Flood (LLOF)	2008	India	Quantitative	[54]	High Quality (HQ)
Consequences of landslide (case study)	2011	India	Quantitative	[55]	Moderate Quality (MQ)
Landslide hazards in Murree	2011	Pakistan	Mixed	[35]	MQ
Direct and indirect losses	2013	India	Quantitative	[56]	HQ
Rock weathering and its effect	2014	Nepal	Quantitative	[57]	HQ
Preventing measures for landslide	2016	India	Mixed	[11]	HQ
Factors influencing the co-seismic landslides	2016	Himalaya	Quantitative	[58]	HQ
Loss and damage by a landslide	2018	Nepal	Mixed	[59]	MQ
Rainfall triggered landslide	2018	Nepal	Quantitative	[60]	MQ
Geographical features susceptible to landslide	2019	Nepal	Quantitative	[61]	HQ
Relation between rainfall and landslide	2019	Bhutan	Quantitative	[62]	MQ
Preventing measures for landslide	2020	India	Quantitative	[63]	HQ
Trend of casualty	2020	Bangladesh	Mixed	[64]	MQ
Rockfall hazards	2020	Nepal	Quantitative	[65]	HQ
Seismic landslide hazard map for assessing the seismic landslide risk.	2021	Himalaya	Quantitative	[43]	HQ
Causative factors of landslide	2021	Pakistan	Quantitative	[66]	HQ
Co-seismic displacement in natural slopes	2022	Nepal	Quantitative	[67]	HQ
Develop strategies for resettling vulnerable people in safe locations	2021	Nepal	Qualitative	[68]	HQ
Comparison of resilience with living in rural, urban, and inner city	2021	Pakistan	Quantitative	[13]	HQ
Characteristics of earthquake-induced landslide	2021	Nepal	Quantitative	[69]	HQ
Prediction of dam bread by a landslide	2022	China	Quantitative	[70]	HQ
Study of avalanche (case study)	2022	India	Quantitative	[71]	HQ
GLOF due to landslide	2022	India	Qualitative	[72]	HQ
Natural Disasters in the Himalayan Region	2022	India	Qualitative	[73]	HQ
Guidelines for managing landslide	2022	India	Quantitative	[74]	HQ

3.1. Spatial Coverage in the Study

Geographically, studies have incorporated Bangladesh 4% [n = 1], Bhutan 4% [n = 1], China 8% [n = 2], Nepal 36% [n = 7], India 32% [n = 9], Pakistan 12% [n = 3], and the Himalayas 8% [n = 2] is also included because it lies in the southern stream of the eastern Himalayas (Figure 4a). Likewise, eastern Himalayas account for 8% [2], central Himalayas for 40% [10], western Himalayas for 44% [11], and all Himalayas account for 8% [2] of the total reviews (Figure 4b). Moreover, the level of analysis varies widely among the research papers. The studies were mainly carried out at the local 44% [n = 11 studies], at the provincial 28% [n = 7 studies], at the national level 16% [n = 4 studies], and Himalaya region level 12% [n = 3 studies]. As per the applied method, 72% [n = 18] of the article used quantitative methods, 12% [n = 3] used qualitative methods, and 16% [n = 4] employed a mixed method.



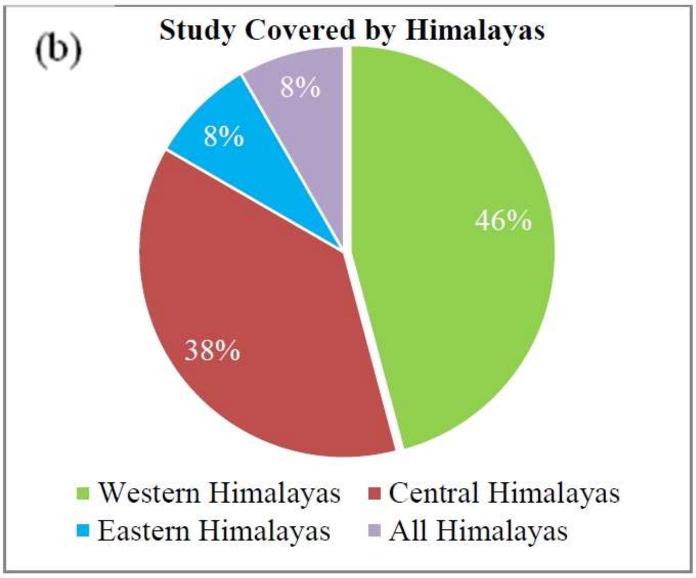


Figure 4. Spatial distribution of landslide studies (**a**) according to countries, and (**b**) in the Himalayas.

3.2. Temporal Coverage of the Study

Of the 25 selected articles, 4% article [n = 1] was published in the year 2008, 8% [n = 2] in the year 2011, 4% [n = 1] in year 2013, 4% [n = 1] in year 2014, 8% [n = 2] in year 2016, 8% [n = 2] in year 2018, 8% [n = 2] in year 2019, 12% [n = 3] in year 2020, 20% [n = 5] in year 2021, and 24% [n = 6] in year 2022 (Figure 5). The Figure 6 shows the increasing trend of the paper that contributes in the study of landslide in Himalayan region. The increasing number of journal articles on landslides in the Himalayan region can be attributed to several factors like growing awareness and concern about the risks and impact of landslides in the region. Again, the effects of climate change and environmental degradation in the Himalayas have heightened the need for research on the relationship between climate change and landslides. The distribution of selected articles as per publication year and its trend has been depicted in Figures 5 and 6, respectively.

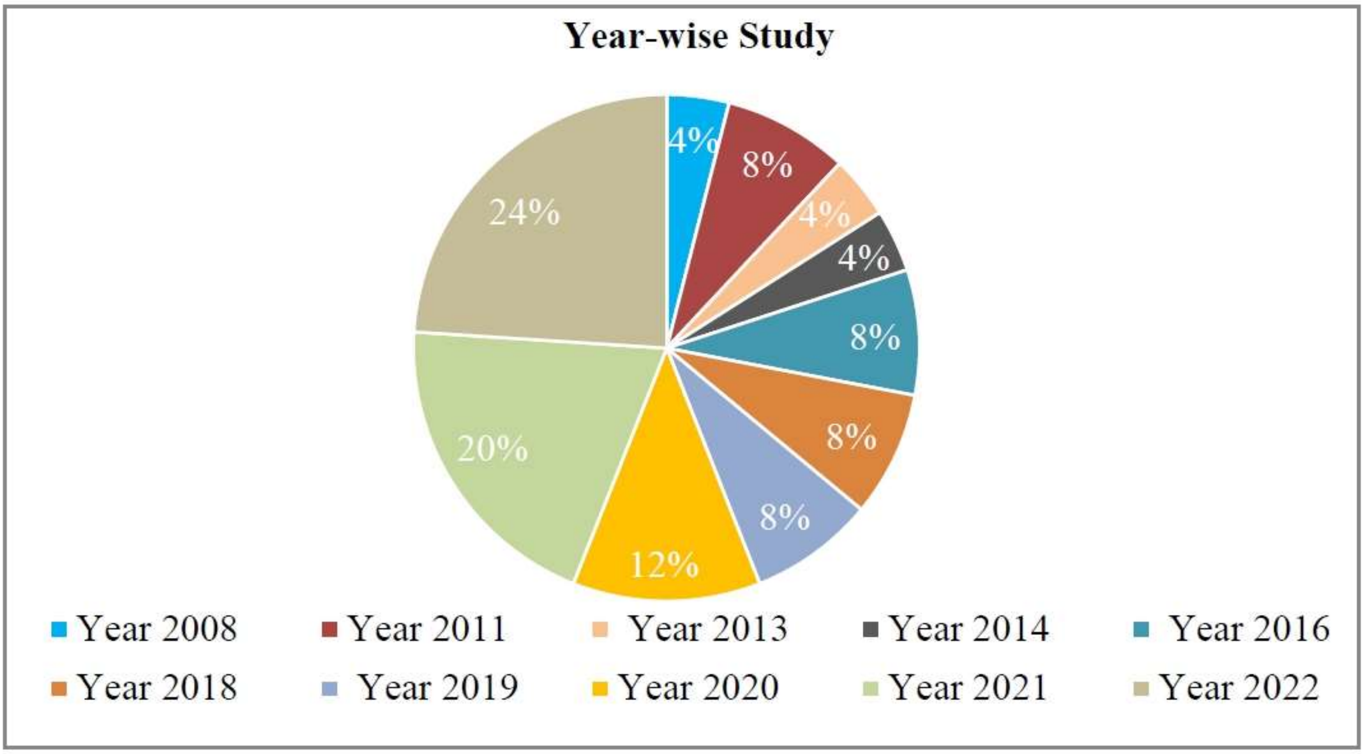


Figure 5. Year-wise classified number of selected articles.

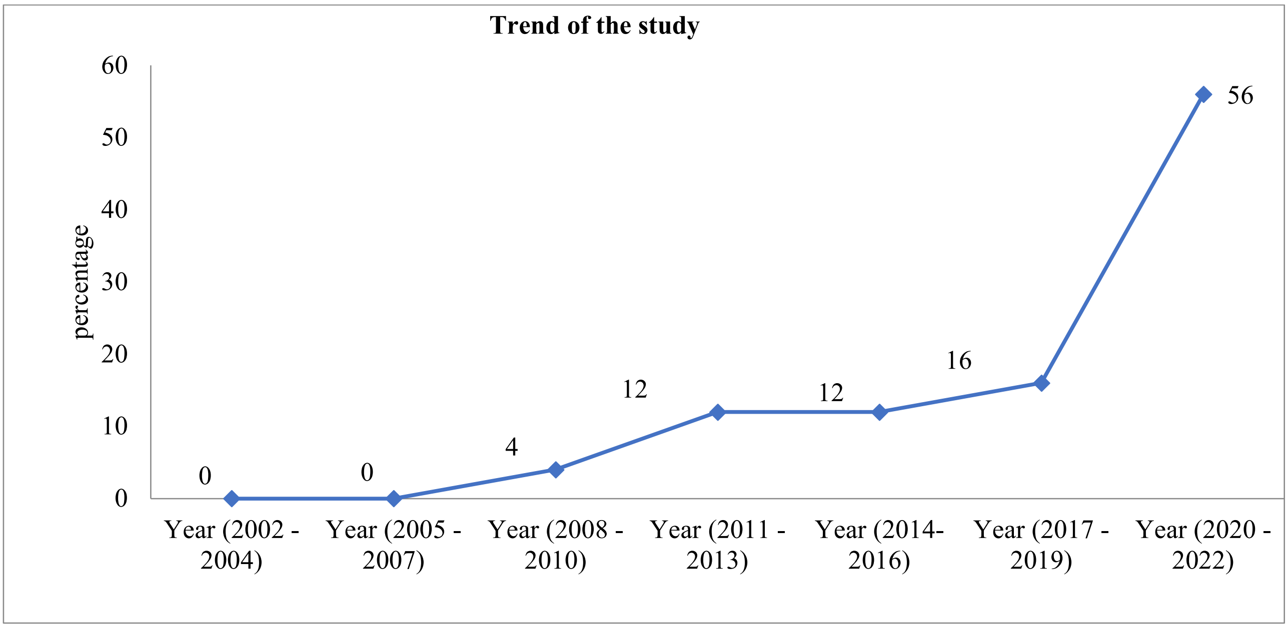


Figure 6. Trend of selected articles.

3.3. Thematic Categorization and Analyses

This article is thematically categorized into main themes and sub-themes. Our first theme is the impact of landslides in the Himalayas, with 21 articles based on Robert Chambers' five livelihood capitals: physical capital [*n* = 4], human capital [*n* = 5], financial capital [*n* = 4], natural capital [*n* = 6], social capital [*n* = 2]. As a second theme, we reviewed 9 articles focusing on the causes of landslides in the Himalayas. We divided the causes of landslides in the Himalayas into three subthemes: natural, geologic, and anthropogenic. Natural causes include climate change-induced landslides; geologic reasons include earthquakes, steep slopes, weathering, weak rock, soil, and depth. Moreover, anthropogenic causes include poorly constructed roads, construction of mega infrastructure, unscientific land use practices, and careless application of technology, disturbing drainage patterns, removing vegetation, and deforestation. The third theme, an adaptive strategy, is also analyzed, which is further divided into proactive and reactive sub-themes in the Himalayas with 15 articles (Table 3).

Table 3. Thematic Categorization and Analyses.

Theme of the Articles	Sub-Theme of Articles	Reference	Number
Impact of landslide	Physical impacts: (Landslide induced fatalities, Rockfall hazards; Loss and damage by a landslide)	[59,63,64,72]	4
	Human impacts: (Building barrier lake by a landslide; Threat of Landslide Lake Out Burst Flood (LLOF) downstream; Rock fall hazards threat to downstream people)	[54,59,64,70,72]	5
	Financial impacts: (Direct and indirect losses due to highway obstruction; Impacts of landslides on income)	[56,59,63,72]	4
	Natural impacts: (Environmental effects; Rock ice avalanche; Glacier-triggered debris flow and flash flood; mud flow, Landslide Lake Outburst Flood; Flood inundation evolution; Building barrier lake by a landslide; Rock fall hazard)	[35,54,64,70–72]	6
	Social impacts: (Social resilience; Participatory approach for housing reconstruction)	[13,68]	2
Causes of landslide in the Himalayas	(a) Natural: (Climate change induced landslide; precipitation; Glacier-triggered debris flow and flash flood; Environmental Degradation)	[11,35,55,58,61,62,64,72,74]	9
	(b) Geologic: (Earthquake; Steep slope; weathering; weak rock type; soil type and depth)		

	(c) Anthropogenic factors: (Poorly constructed roads; construction of mega infrastructure unscientific land use practices; careless application of technology; disturbing drainage patterns; removing vegetation; deforestation; Increasing population, urbanization)		
Adaptive Measures	Proactive: ➢ Establishing early warning systems: Use of the different models to acquire pre-information on rainfall, earthquake, and landslide. ➢ Monitor slope stability ➢ Design drainage structures ➢ Relocation to the exposed and settling in a vulnerable area. ➢ Construction of high-quality structures ➢ Awareness program	[11,62,63,65–67,71,74]	8
	Reactive ➢ Prompt search and rescue program ➢ Instant Compensation and relief strategy; Resettlement of Displaced People ➢ Counseling to the victims	[13,43,59,61,67,68,72]	7

4. Discussion

The Himalayan region is vulnerable to landslides because of its geographical, hydrological, spatial, and meteorological characteristics. The study explored the impacts, causes and adaptive measures of landslide hazards in the Himalayan region, inclusive of India, Nepal, China, Bangladesh, Bhutan and Pakistan. Resilience for the rural fringe is low compared to the urban fringe and the inner city [13]. In this section, the impacts of landslides in the Himalayas and the causes of landslides based on the five livelihood capitals of Robert Chamber have been analyzed. From the review, we found frequent occurrences of hazards such as landslides, snow avalanches, floods and other types of disasters in the Himalayas that resulted in a tremendous loss of physical, human, financial, social, and financial capital. Sultana (2020) reported 204 landslides in Bangladesh between 2000 and 2018, causing 727 death trolls and 1017 injuries [64]. Likewise, Sati (2022) explored the Rishi and Dhauli Ganga glacier outbursts on February 7th, 2021, in the source area of Rishi Ganga, Chamoli district, Uttarakhand [72]. The catastrophe led to the loss of approximately Rs. 20,000 million, claiming the lives of 205 people. Similarly, Shrestha and Bhatta (2021) reported that floods and landslides killed 40,000 people, injured 75,000, and affected another three million people between 1971 and 2015 in Nepal, with yearly losses ranging from 0.10 to 354.38% of the GDP [68]. A study by Gupta and Sah (2008) examined the landslide lake outburst flood from 2000 to 2005 caused by breaching landslide lakes along the Satluj River in Kinnaur, Himachal Pradesh, India, as well as Paree Chu (stream) in Tibet, which caused the loss and destruction of 156 people, 250 houses, 20 km roads, and USD 222 million [54]. Urbanization increases landslide risk due to land alteration, soil erosion, and increased water runoff, reduced water absorption from impervious surfaces. Construction on steep slopes without proper planning can destabilize terrain, exacerbating the hazards [75–77]. Urbanization also concentrates people in high-risk areas, making them more vulnerable. A typical flood can transition into a more destructive mud flood when landslides mobilize loose soil, rock, and other debris into river systems or drainage paths during intense rainfall or rapid snowmelt. The interplay between saturated ground conditions and the influx of additional water increases the sediment load in floodwaters, turning them into viscous mudflows. Mud floods travel rapidly, carrying large volumes of debris, which can cause extensive damage to infrastructure, agriculture, and human settlements. This was observed in Melamchi, Nepal in 2021, when the heavy rainfall triggered landslides that contributed to the mudflow obstructed river channels and caused significant damage downstream [78].

Landslides can destroy the country's road corridors, negatively impacting both the local and national economy. As a result of flooding surges, landslides are common on the highway in the Himalayas [55], for example, landslide disrupts the Kalki Chakra road corridor located in the lesser Himalayas of India during monsoon every year, which affects business transactions negatively. Destruction of roads can also have a severe economic impact due to the inability to transport essential goods to the village [63]. Apart from direct losses, such as casualties, vehicle damage and a road disruption or blockage of the highway due to a landslide, also might be the reason for indirect losses classified as economic losses due to a continuous blockade of transportation [56,72,74]. Moreover, landslides create not only physical and financial losses, but also cause mental and psychological traumatic impacts on the households residing downstream and around the risk-sensitive zones [59,70]. Similarly, rock fall can cause a surge in lake waters that can break a moraine dam, posing a serious threat to downstream communities [65].

Previous studies have discussed three causes of landslides; physical, environmental, and man-made factors [31]. As part of our analysis, we have classified landslides into three categories: natural, geological, and anthropogenic. These three causes can be intertwined with each other. For example, human activities such as deforestation contribute to climate change, leading to landslides. Deforestation, overgrazing, quarrying, excavation of slopes, road construction, increase in the built-up area and improper drainage and sewerage systems are considered anthropogenic reasons [64]. Young and immature geology, highly erodible rocks, steep and abundant irregular slopes and earthquakes are categorized as geological reasons. Climate-induced and intense monsoon rainfalls are natural factors. Slope angle, distance from a stream, drainage density, distance to a road, normalized difference vegetation index, lithology, and distance to faults are the seven causes of landslides [66]. The causes of landslides in the Himalayas are discussed below:

Climate change-induced landslide: Climate change in the Himalayas has led to erratic rainfall and disasters, such as landslides, which have increased the likelihood of glacier lake outburst floods [79]. Prior studies show concern that increasing warming patterns across the Himalayas during the past few decades may also contribute to severe landslides in the near future [72,80].

Geological reason for a landslide: It is believed that co-seismic landslides are the most significant secondary hazard associated with continental earthquakes of high magnitude in the Himalayas [69]. The Himalayas are seismically active zones with earthquake-induced landslides [81]. The following characters with the lands are most susceptible to landslide as 10–20 km of epicenter with 40°–60° of the slope, Southeast and South direction of aspect and 0–5 km North from main central thrust [61,67]. The landslides are concentrated in the nearby areas of the epicenter with a mean slope angle of approximately 40°, ranging from steep slopes to gentle slopes. An epicenter of magnitude greater than or equal to 5 should be considered susceptible to landslides [82]. Moreover, dip angle and fault weight can significantly increase the number of landslides [83]. The number of landslides caused by the 2008 Wenchuan earthquake in China appeared to be higher than those from the 2015 Nepal earthquake [58].

Anthropogenic causes of landslides: Anthropogenic causes of landslides are equally as critical and can be controlled as natural causes, such as precipitation, rainfall infiltration, and earthquakes [5,84,85]. One of the causes of landslides is the alteration of landscapes by people, such as deforestation, slope cutting, agriculture and road construction [11,86]. Logging, grazing, road building, and mining may have contributed to the landslide because such activities alter a slope's natural tendency to move under gravity pressure during heavy rain or earthquakes [35]. During the construction of roads and infrastructures, human activities can disrupt drainage patterns, make unstable slopes, change vegetation patterns, and deforest the area [60]. The expansion of road-building activity in the hill districts is one of the most likely explanations for the increase in landslides and environmental impact, which was observed in Azad Kashmir, Northern Pakistan, and India [40,87,88]. This type of vulnerability is exacerbated by poor infrastructure design in developing countries. Nepal has experienced increased landslide fatalities between 1978 and 2005, largely due to poorly constructed roads [40]. Apart from poor road engineering, mega-construction is also responsible for landslides [89]. The Rishi Ganga disaster shows that the loss of life and property is due to the construction of energy projects [72]. The relationship between human activities and the causes of landslides is shown in Figure 7.

The study has further identified anthropogenic reasons as important factors that could be reduced or minimized by considering adaptive measures in the Himalayas. Construction of mega projects, poorly designed constructions, increased population, increased flow of traffic, and climate change have led to the possibility of landslides in the Himalayas. Moreover, the unpredictable and erratic precipitation in the region caused by climate change has increased the risk of landslides [90]. However, adaptation to landslides in Himalayan countries is limited and challenging because of insufficient resources and limited capabilities [69,91]. Physical prevention and mitigation by engineering are extremely difficult in the Himalayas [69]. However, the situation can be supported by a forecasting mechanism or early warning system. It can be developed as the first line of action [62] to minimize the risk and threat of landslides. It is imperative to consider safer and more sustainable "green road" concepts [92] that assist in controlling erosion activities. Seismic landslide hazard maps are valuable tools in seismically active zones, providing early warnings that can help minimize the risk associated with landslides [43]. Farooq and Akram (2021) propose an integrated model of information value based on a probabilistic approach for mapping the susceptibility of landslides [66]. Likewise, Sur et al. (2020) recommended a fuzzy AHP model in the areas of the Lesser Himalayas which has 86.52% accuracy in landslide prediction.

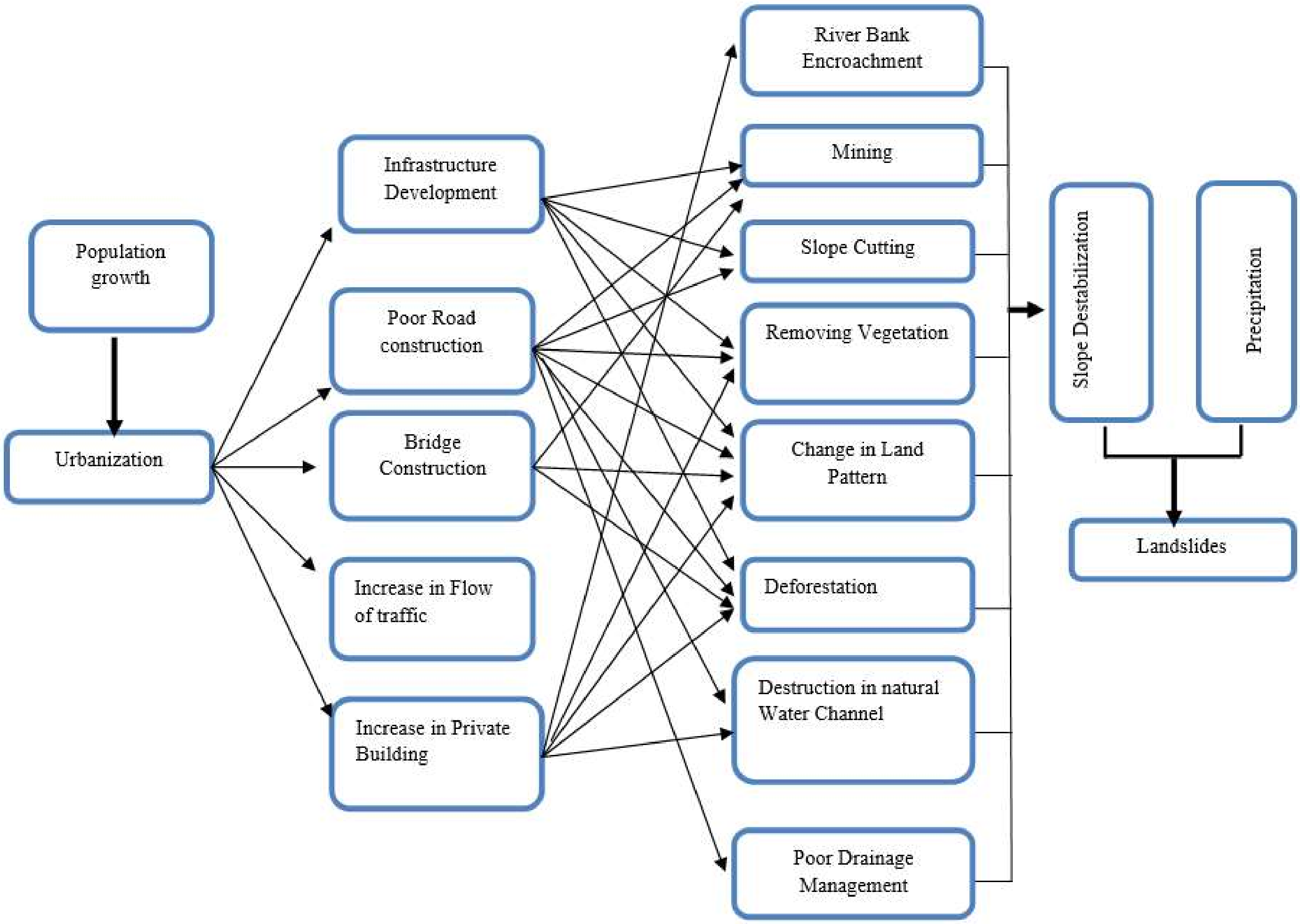


Figure 7. Anthropogenic causes of landslide.

5. Conclusions and Recommendations

This review addressed the current knowledge of the cause and impact of landslides in the Himalayan region. Papers related to the impact of landslides in the Himalayan region, published between 2002 and 2022, have been highlighted. Based on the data synthesis, it can be concluded that the Himalayan region is most vulnerable to landslides, and the trend of research in this area has been increasing over the past few years. According to the findings, the cause of landslides is not only limited to the natural cause but also anthropogenic cause. To address the urgent need for action, this study emphasizes the importance of coordinated efforts among stakeholders, including local, national, and regional governments, as well as community organizations. Given the increasing frequency of landslides in the Himalayan region, driven by climate change and urbanization, there is an immediate need to prioritize landslide risk reduction. Monitoring slope stability in the Himalayas is necessary to achieve regional sustainability.

As part of adaptive capacity, the government should establish early warning systems, disaster contingency plans, strict regulations, emergency funds for disaster situations, and a code of conduct for disaster areas. It is possible to stabilize several shallow slides by designing drainage structures appropriately by channelizing the waters on steep terrain. The engineering and construction of high-quality structures and careful land-use planning are of utmost importance for the people of the Himalayas to reduce landslide risks. The victims should be assisted with counseling facilities to recover from the psychological impact of the incident. Moreover, raising awareness among communities about the risk of landslides and safety measures is essential to minimize the hazard, and a relocation plan should be developed for those at risk. Additionally, future research should focus on advancing early warning technologies, such as remote sensing and predictive modeling, to better anticipate landslide events in the region. Exploring cost-effective, sustainable landslide mitigation solutions is crucial, particularly for resource-constrained areas. Furthermore, research should assess the socio-economic impacts of landslides, focusing on vulnerable communities, and promote cross-border collaboration to share knowledge and develop region-specific adaptive measures.

Author Contributions

M.S.: Conceptualization, Writing original draft, Writing—review & editing, Formal analysis, Investigation, Visualization, Data curation; S.S.: Visualization, Writing—review & editing, Formal analysis; R.P.S.: Conceptualization, Writing—review & editing, Data curation, Formal analysis. All authors have read and agreed to the published version of the manuscript.

Ethics Statement

Not Applicable.

Informed Consent Statement

Not Applicable.

Data Availability Statement

Not Applicable.

Funding

This research did not receive any specific grant from funding agencies.

Declaration of Competing Interest

The authors declare no potential conflicts of interest.

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