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# Analysis of Evolving Flood Patterns and Associated Damages Across Pakistan

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***Abstract*- This paper presents a comprehensive analytical review of the evolving spatio-temporal patterns of floods and associated damages across Pakistan. Understanding these evolving patterns is essential for improving flood risk management and minimizing avoidable flood-induced damage. Numerous studies have investigated different aspects of flood occurrence, flood management practices, and their socio-economic impacts. However, most have focused on individual flood events or specific flood types. Consequently, a holistic assessment of the spatio-temporal evolution of flood patterns and the associated damages under the influences of climate change and anthropogenic activities is still required. To address this research gap, an extensive literature review was conducted and historical flood data was compiled to investigate the long-term evolution of different flood types across Pakistan. Heat maps of annual peak discharges recorded at major dams, barrages, and hydraulic control points were developed to analyze the temporal and spatial evolution of flood patterns. The analysis revealed that 13 distinct flood types have been reported in Pakistan over the past 75 years, encompassing classifications based on physical origin, geographical setting, flood onset characteristics, and special triggering mechanisms. Among these, riverine, cryospheric, and rural floods have been the most persistent flood types, whereas urban flooding, Glacial Lake Outburst Floods (GLOFs), and pluvial flooding have become frequent in recent decades. The historical analysis further indicates that severe flood events with exceptionally high peak discharges were more common during the period 1970–2000, whereas recent decades have experienced a higher frequency of flood events with comparatively lower peak magnitudes. The simultaneous occurrence of multiple flood types has resulted in compound flooding in 2010, 2020, and 2022 causing exceptionally severe impacts across Pakistan. In particular, the 2022 flood affected more than 33 million people, resulted in the loss of approximately 1.16 million livestock, and damaged approximately 2.29 million houses, that makes it one of the most devastating flood disasters in Pakistan's recorded history.**

***Index Terms*—Flooding Types, Pakistan, Evolving Flood pattern, Flood damages, GLOF, Urban flooding.**

## I. Introduction

Floods are among the most destructive natural hazards worldwide. Their frequency has increased in recent decades, while their impacts on human lives and infrastructure have intensified because of rapid urbanization [1]. Between 1990 and 2022, floods affected approximately 3.2 billion people worldwide, resulting in nearly 218,000 fatalities and economic losses exceeding US$1.3 trillion [2]. According to the World Bank Group (2020) [3], approximately 992 million people were exposed to flood hazards in 2010, and this number was projected to increase to 1.3 billion by 2050 [4]. However, a subsequent study [5] reported that the number of people exposed to flood hazards had already exceeded this estimate by 39%.

Furthermore, satellite-based analyses have revealed that the global flooded land area has increased by 14.2% [2]. Previous studies have also reported that flood risk is likely to increase under a warmer climate [6]. Although several studies have assessed the impacts of flooding on affected populations and regions, relatively few have quantified the future increase in flood hazards attributable to climate warming [7]. According to the Clausius–Clapeyron thermodynamic relationship, the atmospheric water-holding capacity increases by approximately 6–7% per 1°C increase in air temperature [8], [9]. Consequently, a study by [10] suggested that a 2-3°C increase in temperature could increase flood-related fatalities by 50% or more.

The Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change concluded that anthropogenic greenhouse gas (GHG) emissions since the pre-industrial era have increased the frequency of extreme precipitation events, and continued increases in GHG concentrations are expected to further intensify global warming [11]. The report further projects that, under 1.5°C of global warming, both the frequency and intensity of heavy precipitation and flooding are likely to increase across many regions of Africa and Asia [11].

Flood frequency is increasing worldwide due to combined effect of climatic and anthropogenic factors. Globally, floods are one of the most destructive natural hazards, causing substantial damages in form of lives lost and infrastructure destruction. The IPCC Sixth Assessment Report [11] further indicates that anthropogenic climate change has intensified the global hydrological cycle, increasing the frequency and magnitude of heavy precipitation events in many regions. At the same time, rapid urbanization, expansion of settlements onto floodplains, population growth, old drainage infrastructure, and coastal land subsidence have substantially increased flood exposure and vulnerability [5]. As a result, flood hazards are no longer confined to developing countries but affect both developed and developing countries. This shows, floods as a global challenge which require adaptive management rather than solely structural protection [2].

In august 2024, Bangladesh faced flash flood which affected more than five million people after intense monsoon rainfall. This was attributed to global warming and climate change which enhanced the precipitation and limitations in early warning communication, which collectively intensified disaster impacts. Similarly, Austria, and Poland experienced intense rainfall exceeding 300 mm in some areas, demonstrating that even countries with advanced flood management systems remain vulnerable when rainfall exceeds historical design assumptions [2]. In Spain, catastrophic floods in the Valencia region received more than 250 mm of rainfall within 24 hours. Rapid urban development on historical floodplains and inadequate drainage infrastructure significantly increased flood damages [2]. These international experiences prove that modern flood disasters are gradually governed by the interaction between changing climate and anthropogenic factors including urbanization, floodplain encroachment, and infrastructure limitations. Similarly, these drivers are increasingly evident across Pakistan, highlighting the need for combined flood forecasting and adaptive flood management strategies [2], [5], [11]

### *A. Flood Risk in Pakistan*

Pakistan is highly vulnerable to flooding because of its climatic and hydrological characteristics. Flood events primarily occur during the monsoon season (July to September). During this season intense monsoon precipitation associated with monsoon depressions generates substantial runoff throughout the Indus River Basin. On the other hand, the winter season (December to February) is characterized by a different hydrometeorological regime, influenced by western disturbances [12], [13].

Pakistan has experienced many severe flood events in recent decades, which resulted in substantial human, social, and economic losses. Climate change and global warming have been globally recognized as the important factors, which is contributing to the increased frequency and severity of these flood events [14], [12], [13], [15].

Hydrological regime of Pakistan has undergone major changes associated with climate change. Rising of air temperatures, accelerated glacier melt and shifting of precipitation patterns, have changed the hydrological processes governing river flows across the country. Historical records from 1900-2000 shows continuous increase in average annual temperature and projections suggesting an additional increase of 0.9-1.5°C by 2050. Such variations are expected to intensify extreme precipitation events and accelerate glacier melt, resulting in rate of flood risk throughout the Indus River Basin. According to the Germanwatch Global Climate Risk Index, Pakistan ranked among top ten countries which are most affected by climate related hazards over the previous two decades. During this period, 153 extreme weather events resulted in approximately 10,000 fatalities [16], [17], [18].

Different governmental organizations have implemented structural and nonstructural measures to reduce flood risk. These initiatives remained insufficient to efficiently mitigate impacts of flood. Consequently, further developments in flood forecasting systems are required along with early warning, and integrated flood management systems. These steps are essential to facilitate timely mitigation measures and minimize flood related losses [14].

### *B. Types of Floods in Pakistan*

Due to Pakistan diverse geography, climatic, and hydrological conditions Pakistan experiences a wide variety of flood types. It is essential to distinguishing among these flood types because each type requires specific datasets and forecasting methodologies and disaster management strategies. A generalized taxonomy of floods is presented in Figure 1. Proposed taxonomy classifies floods into four principal categories based on (a) water source and physical origin, (b) geographical location of occurrence, (c) onset rate and flood duration, and (d) structural or triggering mechanisms.

Based on water source and physical origin, four major flood types occur in Pakistan:

1. Riverine floods: This type occur when river discharges exceed the channel conveyance capacity.
2. Cryospheric floods: This originate from seasonal snowmelt and glacier melt within upstream catchments.
3. Pluvial floods: This is the result of intense rainfall, causing surface water accumulation and overland flow.
4. Coastal floods: This flood inundate low lying coastal areas along the Arabian Sea coastline.

Based on occurrence of these floods, they can be further classified as urban floods, rural floods, and mountainous/valley floods. When classified according to onset rate and flood duration, they may be categorized as flash floods, slow onset floods, and cloudburst induced floods. Further, flooding may be triggered by mechanisms which includes glacial lake outburst floods (GLOFs), artificial dam failures, and debris dam failures. Detailed classification of these flood types is presented in Figure 1. Overall, 13 distinct flood types have been identified in Pakistan.

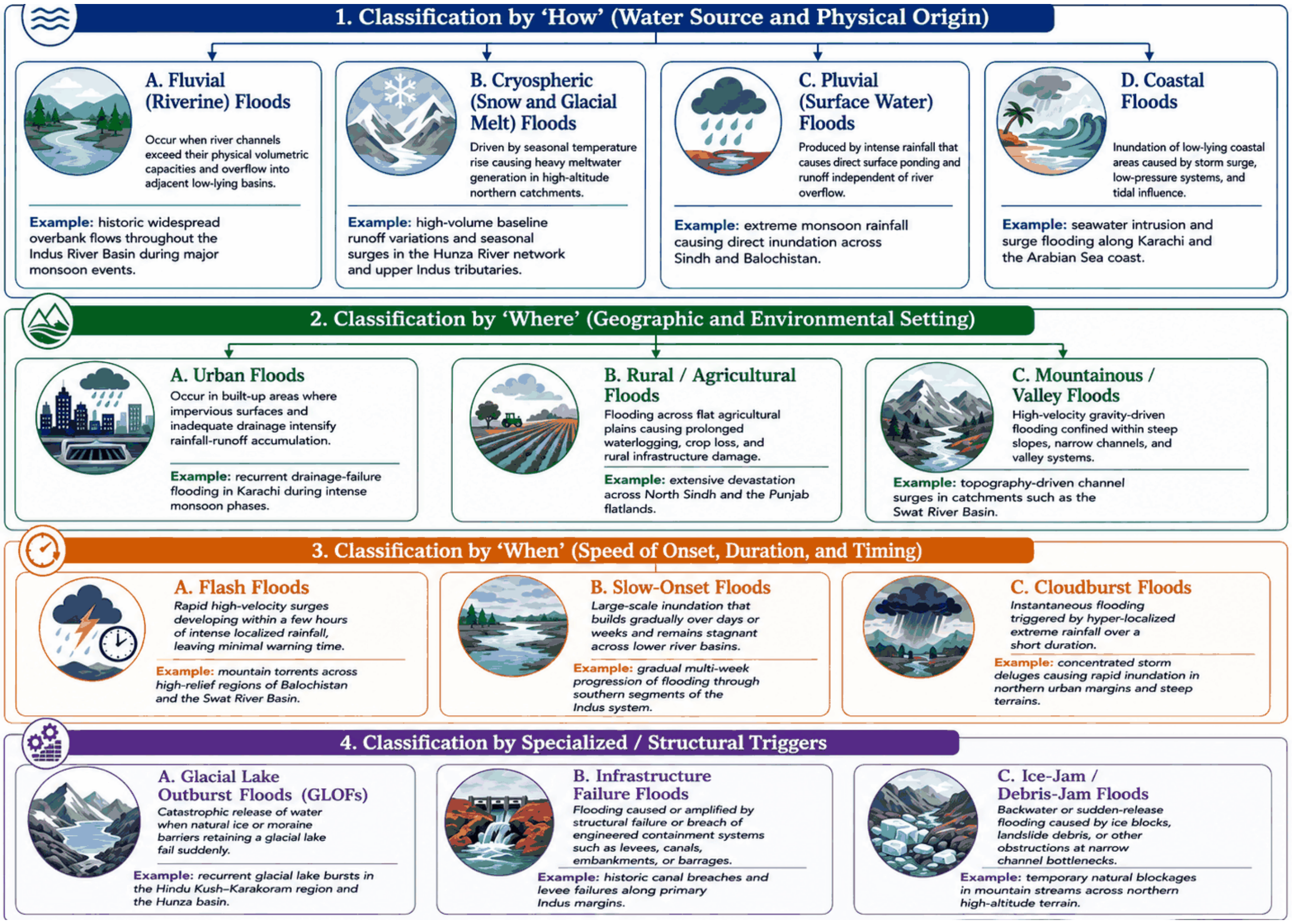


Fig. 1. Taxonomy of floods

Riverine floods in Pakistan typically require several days to propagate from the northern catchments to the floodplains of Punjab and Sindh before ultimately discharging into the Arabian Sea. These floods occur when monsoon driven river discharges exceed channel conveyance capacity, causing overbank flow and inundation of adjacent floodplains. Cryospheric floods include snowmelt- and glacier melt-induced flooding, which is primarily associated with the high-mountain catchments of the Hindu Kush–Karakoram–Himalaya (HKH) region. Seasonal snowmelt and glacier melt increase baseflow and can generate significant meltwater surges.

Pluvial floods, also referred to as surface water floods, occur when rainfall intensity exceeds the local infiltration capacity and the capacity of stormwater drainage systems, resulting in surface inundation even in the absence of river overflow. In contrast, coastal floods occur along low-lying coastal areas of Sindh and Balochistan because of storm surges, cyclone-induced wind setup, high tides, and seawater intrusion. Pluvial flooding in urban areas is considered as Urban flooding, it has emerged as an increasingly significant hazard in Pakistan as a consequence of rapid urbanization making cities such as Karachi, Lahore, Rawalpindi, and Hyderabad particularly vulnerable. Efficient urban flood management requires advance rainfall runoff modelling integrated with suitable designed storm water drainage systems.

On the other hand, rural and agricultural floods are classified as one whose prolonged water stagnation causes extensive waterlogging over low lying agricultural lands. While, mountainous and valley floods are fast and high energy events confined within steep valleys and narrow catchments, producing highly destructive flood surges in regions, for example Swat, Chitral, Gilgit-Baltistan, and other northern mountainous areas. Unlike slow onset riverine floods, which develop gradually, flash floods are intense hydrological events that develop rapidly and often within a few hours of intense rainfall or sudden flow release provides very limited time of warning. Conversely, slow-onset floods evolve over several days or even weeks as floodwaters propagate through the lower reaches of the river system and remain stored within extensive floodplains for prolonged periods.

Cloudburst floods constitute a distinct subtype of high-intensity rainfall-induced flooding, generated by highly localized, short-duration precipitation events that produce near-instantaneous runoff, urban inundation and flooding within narrow valleys. In glacierized mountain regions, Glacial Lake Outburst Floods (GLOFs) represent one of the most destructive forms of flash flooding. These events occur when the natural dam impounding a glacial lake fails, releasing large volumes of water and sediment downstream. Infrastructure failure floods occur because of the breach or failure of hydraulic structures, including canals, barrages, levees, flood embankments, or drainage systems subjected to excessive hydraulic loading. Finally, ice jam or debris jam floods are localized backwater or sudden release flood events caused by multiple factors, such as obstruction of river flow by accumulation of ice, landslide debris or sediment deposits at channel constrictions specifically in mountainous river systems.

As summarized in Table I, each flood type shows distinct hydrological and geomorphological characteristics which makes it necessary to develop hazard specific forecasting approaches and relative mitigation strategies for effective flood risk management [16], [12]. For example, forecasting for GLOFs requires continuous monitoring of glacial lakes in conjunction with thermal and remote sensing observations. On the other hand, torrential and flash floods are characterized by extremely short response times. Necessitating the need for real time rainfall observations, high resolution weather forecasts, and physically rainfall runoff models to get maximize flood warning lead times. Such flood events are predominantly reported in Khyber Pakhtunkhwa (KP), Azad Jammu and Kashmir (AJK), Balochistan, and the Dera Ghazi Khan (D.G. Khan) region of Punjab.

The documented occurrences of these flood types in Pakistan, as reported in previous studies, are summarized in Table 1, including riverine (fluvial) floods [19], [20], cryospheric floods [21], [22], pluvial floods [23], [24], coastal floods [25], urban floods [26], rural floods [27], mountainous floods [28], flash floods [29], slow-onset floods [30], cloudburst floods [31], Glacial Lake Outburst Floods (GLOFs) [32], infrastructure failure floods [33], and ice-jam/debris-jam floods [34]. The corresponding hydrological, hydraulic, and geomorphological characteristics of each flood type are also presented in Table I.

Since different flood types are generated by different hydrometeorological and geomorphological processes, each requires a dedicated approach for flood forecasting, hazard assessment, risk evaluation, and management.

Table I
Main flood types in Pakistan

| Flood type | Operational definition in Pakistan context | Ref |
|---|---|---|
| Fluvial (Riverine) floods | River discharge exceeds bankfull capacity and spills over the floodplain; dominant along the Indus River Basin during high monsoon flows. | [19, 20] |
| Cryospheric (snow and glacial melt) floods | Accelerated melting of snowpack and glacier ice elevates baseline flows and produces meltwater surges in glacier-fed catchments such as Hunza and upper Indus tributaries. | [21, 22] |
| Pluvial (surface water) floods | Direct inundation caused by rainfall accumulation exceeding infiltration and drainage capacity, independent of river-channel overflow. | [23, 24] |
| Coastal floods | Inundation of low-lying coastal land caused by storm surge, cyclonic wind set-up, high tides or seawater intrusion along Sindh and Baluchistan coasts. | [25] |
| Urban floods | Waterlogging and inundation in built-up areas where impervious surfaces and inadequate stormwater drainage intensify runoff; recurrently observed in Lahore and Karachi. | [26] |
| Rural / agricultural floods | Prolonged waterlogging over low-gradient farmland that damages crops, rural settlements and infrastructure, especially in North Sindh and Punjab plains. | [27] |
| Mountainous / valley floods | High-velocity flood flows confined within steep valleys and narrow catchments, producing destructive surges such as those in the Swat River Basin. | [28] |
| Flash floods | Floods that develop and peak within about six hours of rainfall or structural failure, leaving little warning time; common in high-relief Baluchistan and Swat Basin terrain. | [29] |
| Slow-onset floods | Large-scale floods that build gradually over days to weeks as floodwater moves through the lower river system and remains over floodplains for extended periods. | [30] |
| Cloudburst floods | Extremely intense, localized rainfall events, often exceeding 100 mm within about an hour, producing near-instantaneous flash inundation in steep or urbanized catchments. | [31] |
| Glacial Lake Outburst Floods (GLOFs) | Sudden release of impounded water when an ice or moraine dam retaining a glacial lake fails; common in the Hindukush-Karakoram and Hunza basin. | [32] |
| Infrastructure failure floods | Flooding caused by breach or failure of flood-control structures such as canals, barrages, levees and embankments under excess hydraulic load. | [33] |
| Ice-jam / debris jam floods | Localized backwater flooding caused by ice blocks, debris or sediment jams obstructing flow at narrow channel bottlenecks in mountain streams. | [34] |

## C. *Flood Management Institutions in Pakistan*

Flood management in Pakistan is implemented through a multi-institutional framework (Fig. 2) involving meteorological monitoring, hydrological observations, flood forecasting, disaster risk management, and policy coordination. The Pakistan Meteorological Department (PMD) and the Water and Power Development Authority (WAPDA) are primarily responsible for hydro-meteorological observations.

Meteorological data generated by the PMD are integrated with river discharge records, reservoir water levels, and hydrological observations collected by WAPDA, together with discharge data received from the Provincial Irrigation Departments (PIDs), by the Flood Forecasting Division (FFD) [35] in Lahore to generate flood forecasts and issue early flood warnings [13].

The Federal Flood Commission (FFC) is responsible for national level flood management policy, strategic planning, and coordination of structural and non-structural flood protection measures. In addition, the FFC compiles and publishes annual flood reports documenting recorded flood events, peak discharges, and the associated human, agricultural, and infrastructure damages.

Flood forecasts and warning bulletins generated by the FFD are communicated to the National Disaster Management Authority (NDMA), which is responsible for disaster preparedness, emergency response, and national level disaster coordination. The NDMA, in collaboration with the Provincial Disaster Management Authorities (PDMAs) and District Disaster Management Authorities (DDMAs), disseminates flood warnings, coordinates emergency response operations, implements contingency plans, and supports affected communities during flood events [13].

The effectiveness of this institutional framework depends on timely, continuous, and efficient coordination and information exchange among all participating agencies. Weaknesses in any component of the system, including limitations in data sharing, inadequate monitoring coverage, forecasting uncertainties, or delays in information transmission, can adversely affect operational response and reduce the overall effectiveness of flood management efforts [13].

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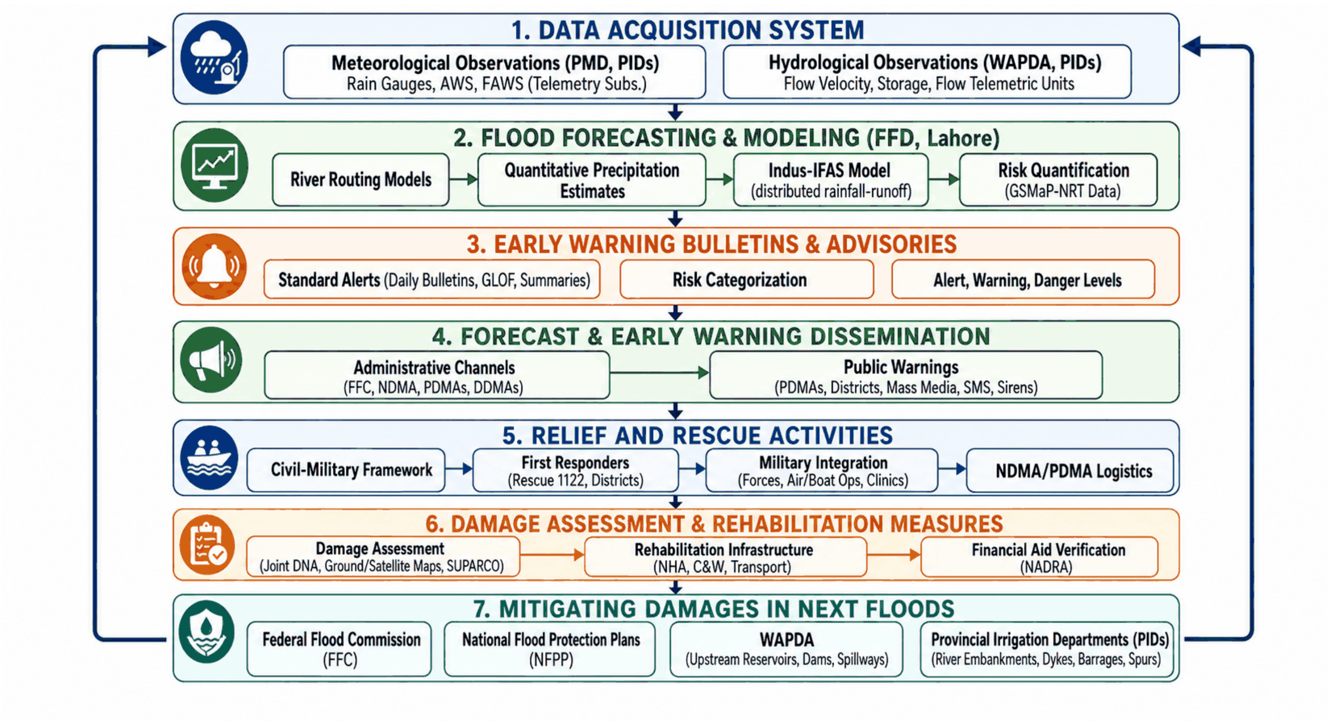


Fig. 2. Flow chart of Flood Management Mechanism

## D. *Efficiency of Flood Risk Management System*

Flood risk management comprises multiple interrelated components extending beyond pre-flood preparedness, including: (i) flood forecasting, (ii) dissemination of early warnings, (iii) emergency preparedness, response, and relief operations, (iv) post-flood damage assessment, and (v) recovery and rehabilitation. Effective flood forecasting relies on the accurate assessment of key hydrological and meteorological indicators governing flood generation and propagation. These indicators typically include rainfall intensity and duration, snowmelt contribution, watershed storage conditions, catchment characteristics and area, seasonal timing of flood events, and watershed runoff response. The availability of accurate and timely data for these indicators enables forecasting models to reliably predict flood events and issue early warnings with sufficient lead time. Conversely, the absence of high-quality observational data increases forecasting uncertainty and reduces the reliability of flood hazard assessments [16].

Similarly, the timely dissemination of actionable flood warnings to the relevant stakeholders is critical for minimizing avoidable losses through prompt emergency response and evacuation. Although post-flood damage assessment, recovery, and rehabilitation are long-term processes, they provide valuable information for reducing future flood risk, particularly when damaged infrastructure is reconstructed or upgraded to enhance resilience against subsequent flood events.

Despite continuous improvements, Pakistan's flood management framework continues to face several operational and technical challenges, including gaps in the hydrometeorological monitoring network, limitations in real time hydrometeorological data acquisition, difficulties in transmitting observations from remote monitoring stations, uncertainties in flood forecasting models, inadequate inter agency data sharing and coordination, delays in the dissemination of flood warnings, and limitations in emergency response capacity. Even though, this institutional framework has contributed significantly to reducing flood impacts, flood continue to cause major human casualties and extensive damage to different sectors.

Considerable efforts have been undertaken in recent decades to strengthen Pakistan's flood risk management system. Nevertheless, the available historical records indicate that these improvements have not resulted in a corresponding reduction in flood-induced damages [12]. In particular, the catastrophic flood events of 2010 and 2022 demonstrated that Pakistan's existing flood management infrastructure and institutional framework remain insufficient to effectively cope with extreme and increasingly unpredictable hydrometeorological events [15].

### *E. Research Gap and Study Objective*

Numerous studies have documented flood events and assessed the associated flood-induced damages in Pakistan; however, the majority have focused on individual flood events, a single hydrological year, or flood events that occurred in the recent past [36], [37], [38]. Although a limited number of studies have undertaken historical analyses of specific flood events [29], [39], [40], comprehensive assessments of the spatiotemporal evolution of different flood types, their changing occurrence patterns, and the associated flood-induced damages across Pakistan remain scarce. Accordingly, the objective of this study is to identify the different types of reported flood events in Pakistan and investigate the historical evolution of flood occurrence patterns and the associated flood-induced damages across the country, considering the potential influence of climate change and anthropogenic drivers.

## II. Material and Methods

The flowchart illustrating the adopted methodology is presented in Fig. 3. The study encompasses various flood types across Pakistan over the period 1950-2024. An extensive search of official records was conducted to obtain detailed information on flood events that occurred between 2010 and 2024.

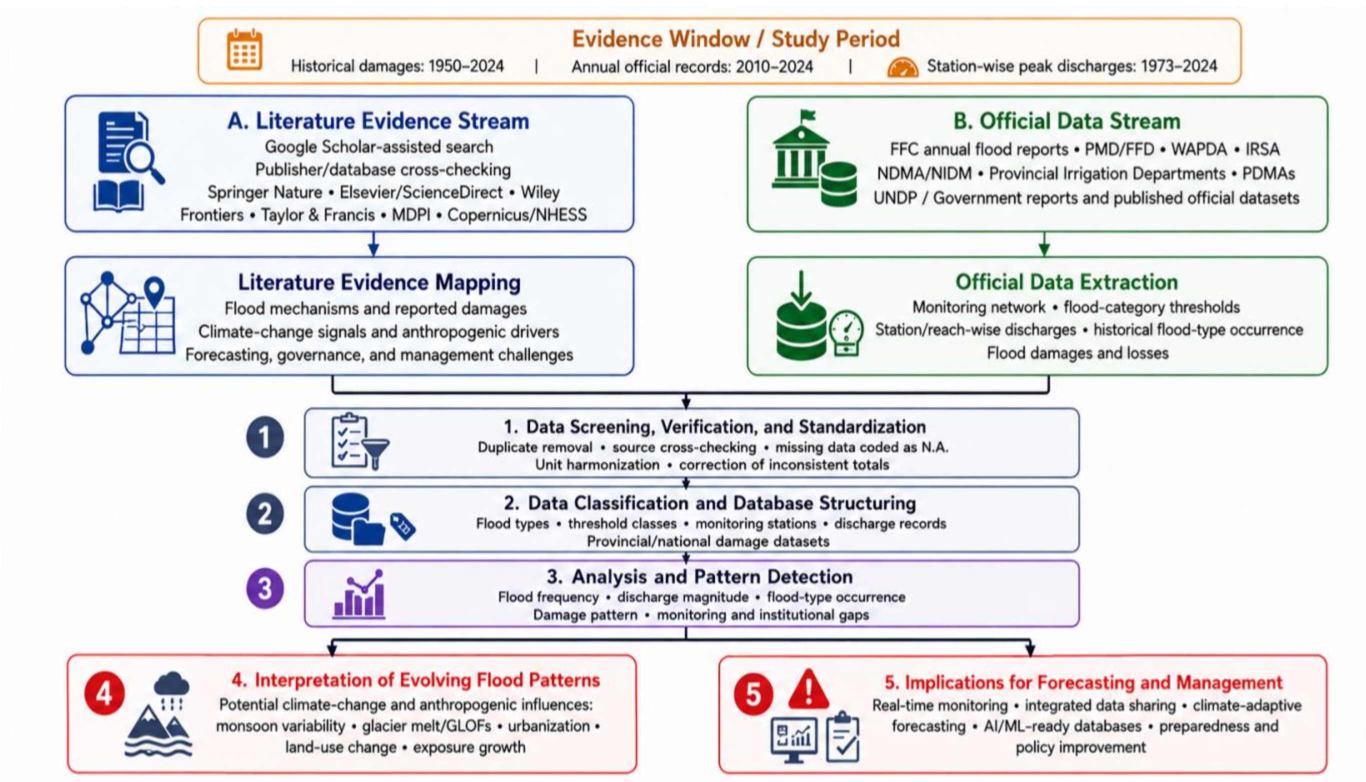


Fig. 3. Flowchart of Adopted Methodology

### *A. Literature Search*

The literature relevant to this study was collected through a systematic Google Scholar assisted search to identify pertinent research articles published by reputable publishers and databases, including Springer Nature, Elsevier/Science Direct, Wiley, Frontiers, Taylor & Francis, MDPI, and Copernicus. The retrieved literature was reviewed to identify flood mechanisms, flood types, historical occurrences, and the associated reported damages in Pakistan. Furthermore, evidence of climate change and anthropogenic influences on flooding was examined to identify the key challenges associated with flood management.

### *B. Data Collection*

Authentic and reliable data on historical peak discharges and associated flood damages were compiled from Federal Flood Commission (FFC) Annual Flood Reports**,** Pakistan

Meteorological Department/Flood Forecasting Division (PMD/FFD) reports, and the official databases and websites of WAPDA, NDMA, PDMA, and the Provincial Irrigation Departments (PIDs), including flood peak records and flood categorization threshold limits. In addition, relevant UNDP reports and officially published datasets from various government agencies were used to extract information on: (a) the flood monitoring network; (b) flood-category threshold limits; (c) station-/reach-wise annual peak discharges and historical occurrences of various flood types; and (d) flood-induced damages.

*C. Data Processing*

The collected data were screened, verified, and standardized prior to analysis. During this process, data obtained from multiple sources were cross checked, duplicate records were removed, measurement units were harmonized, and missing values were coded as N.A. Subsequently, the dataset was structured according to the study requirements to identify historical peak discharges, design discharge capacities, and flood category discharge threshold limits at each regulatory station along the major rivers. Furthermore, annual flood-damage data spanning 1950-2024 were compiled and processed to assess flood-induced damages.

*D. Data Analysis and Graphical Plotting*

At each monitoring station, peak discharges are classified into five flood categories: low, medium, high, very high, and exceptional. This classification was used to evaluate the relationship between flood-category threshold limits and the corresponding design discharge capacities to identify stations where the design capacity has been approached or exceeded by specific flood categories. Subsequently, the processed discharge data were analyzed and visualized using heat maps to illustrate the spatial and temporal variations in peak discharges recorded at the major monitoring stations and to identify changes in historical flood patterns. The historic floods data used in this study were compiled by using official government reports (FFC, FFD, PMD) and organized into tabular form prior to visualization. Chat GPT was used only as an AI assisted coding tool to help the author to convert the prepared tables into Python scripts, which were later executed in Google Colab to generate multidimensional graphical representations of flood patterns along with associated damages. For instance, the maximum historical peak discharge at each monitoring station was plotted against its year of occurrence. Similarly, the temporal occurrences of different flood types were analyzed to evaluate the evolution of flood patterns over time. In addition, the potential influences of climate change and anthropogenic activities on flood occurrence frequency, flood magnitude, and time to peak were critically examined in light of the compiled datasets and the available literature. Finally, annual records of different categories of flood induced damages were analyzed to determine the patterns of flood damages across Pakistan.

*E. Data validation, harmonization, and uncertainty treatment*

The used hydrological dataset was compiled from different official national sources which includes Pakistan Meteorological Department (PMD), Flood Forecasting Division reports (FFD), Federal Flood Commission (FFC) annual flood reports, and associated agency records from WAPDA, PIDs and IRSA as reported in their official flood related documentations. The extracted variables were first organized before comparison by using graphs because these institutes have different method of operations. PMD/FFC annual reports were used as a main source for data of maximum seasonal inflow and maximum reported discharge values where these variables were explicitly tabulated. Where an official source reported only "peak discharge" rather than separately distinguishing inflow and outflow, the original terminology was tried to retained to avoid over interpretation.

Data validation was carried out using four steps. Firstly, all names of river and their station names and units were standardized, with discharge values reported uniformly in cusecs. Secondly, annual and seasonal maximum values were checked against the original PMD and FFC tables, figures and report narratives. Third, where values differed among official sources, the source closest to the variable definition was prioritized; for example, PMD/FFD values were retained for inflow or observed peak discharge, while FFC values were retained for outflow. Fourth, missing or unavailable values were marked as "NR" rather than treated as zero. This distinction is important because absence of a reported value does not imply absence of flow.

Some unavoidable limitation was faced by authors when datasets from multiple institutions was combined. The datasets differ in several parameters like temporal resolution and coverage of station and used terminology. Reports from PMD focused on observed river peaks during the flood seasons, whereas reports from FFC documents several parameters like management of flood, reservoir releases and historical discharges. Therefore, maximum inflow and maximum outflow values should be interpreted as independently reported values. Furthermore, historical records may contain uncertainty due to overtopping of gauge, instrumentation damage during extreme floods, changes in rating curves, manual versus automated data collection, incomplete reporting for some stations or years, misinterpretation of available data. These uncertainties were handled by retaining original source terminology to maximum extent and by reporting missing values.

The reason for using multiple official datasets was because no single national institution report provides all the variables required for the present comparison. For example, PMD/FFD reports provide the most direct source for meteorological conditions and observed flood peaks during flood seasons, while FFC reports provides barrage discharges, reservoir operations and historical flood summaries of Pakistan. In order to organize and compile a complete inflow, outflow and historical flood dataset multiple official sources were necessary. However, the analysis does not assume that all sources are directly interchangeable, instead, each source was used according as per their reported variable.

## III. Result and Discussion

### *A. Spatial Distribution of Flood Monitoring Stations Across Pakistan*

Figure 4 shows paths of the major rivers of Pakistan along with locations of discharge monitoring stations, barrages, and other hydraulic control structures. The flow path and spatial distribution of monitoring stations indicates the routing length of flood wave propagation throughout the Indus River Basin.

The monitoring stations are along the main stem of the Indus, Jhelum, Chenab, Ravi, Sutlej, and Kabul rivers. These stations act as critical control points where flood magnitudes are monitored and classified to support operational flood forecasting and flood management related decision making.

Accuracy of flood forecasting in Pakistan depends not only on availability of catchment rainfall and upstream discharge data but also on other factors like reliability of hydrological observations, selection and validation of rainfall-runoff and runoff routing models. Whereas, effectiveness flood forecast in flood management depends on lead time of the forecast. However, the discharge forecast lead time is limited to 24 hours, despite discharge travel time in days in certain river reaches [35], which has proven insufficient to prevent avoidable damages especially in remote areas. Likewise, effective flood management requires a basin wide, integrated operational approach rather than making decisions solely on the basis of observed or forecasted inflows in an individual river. However, flood management authorities have limited operational flexibility to regulate storage in the Tarbela and Mangla reservoirs to delay and attenuate flood peaks in the Indus and Jhelum rivers, respectively. Furthermore, under a system wide operational strategy, flood waves from different rivers are routed sequentially, wherever feasible, to minimize peak synchronization at river confluences. Similarly, the operation of the remaining rivers is coordinated in an integrated manner to minimize cumulative flood peak amplification throughout the river system to the maximum extent practicable.

Despite these operational measures, historical flood events have resulted in significant loss of human life and extensive damage to livestock, public infrastructure, and private property because of the inherent physical and operational constraints of the river system.

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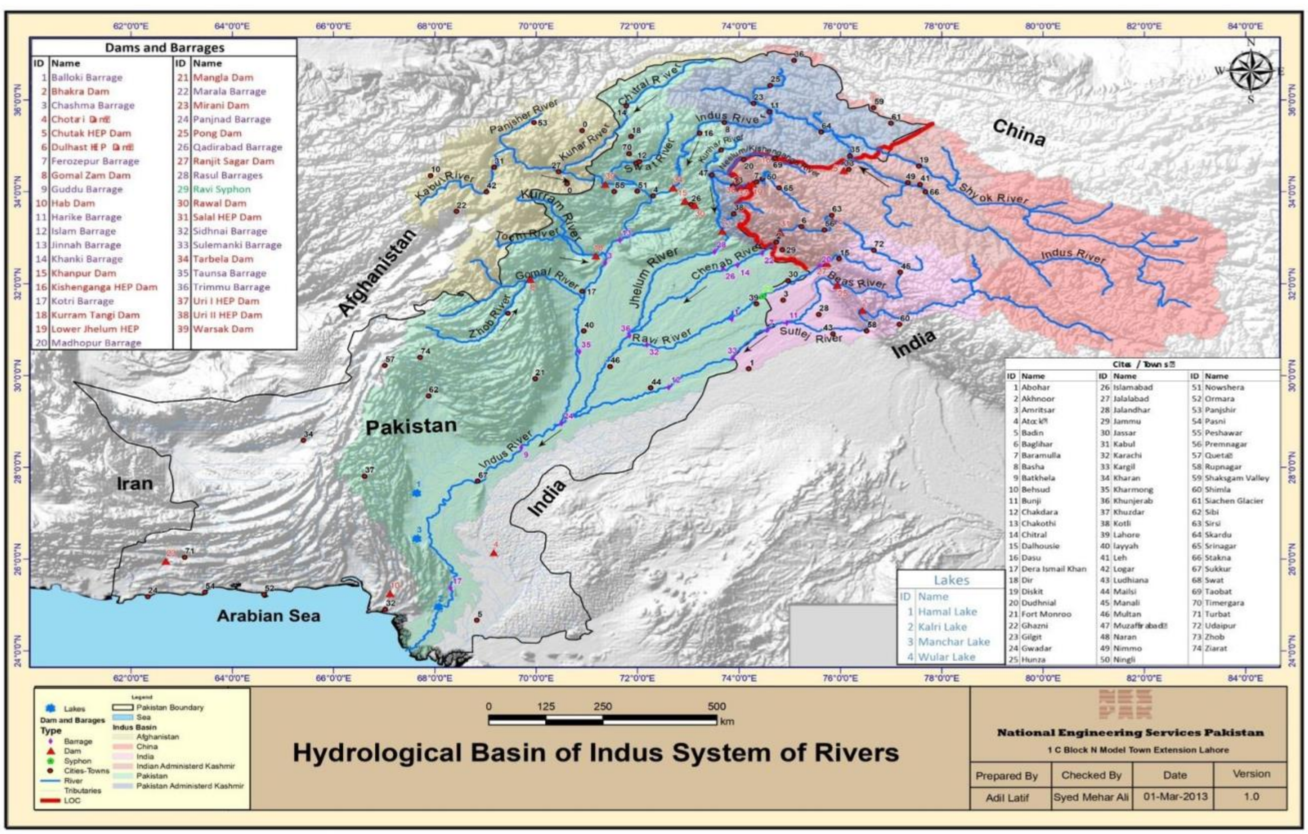


Fig. 4. Pakistan River Network and Flood Monitoring Stations ([Hydrological Basin of Indus System of Rivers]) From The Ministry of Water Resources Pakistan (https://mowr.gov.pk/Detail/NTcwZGFlMTctOGNhYy00M2YyLTliMDAtMzU0OGU5YTlmZWZk)

Generally, it is not feasible to completely prevent flooding through structural measures or to eliminate flood induced damages under all hydrological conditions. Consequently, practical flood management strategies focus on minimizing avoidable damages through an integrated combination of structural and nonstructural measures. Pakistan possesses limited operational flexibility through its system of dams and barrages (Figure 4) to regulate and attenuate flood peaks, however, this regulatory capacity becomes increasingly ineffective during extreme flood events. During exceptionally large floods, controlled breaching of river embankments may become necessary in some cases to protect major urban centers and critical hydraulic infrastructure. Consequently, greater reliance is placed on nonstructural flood management measures to reduce flood caused losses. However, the limited availability of up to date flood hazard and risk zonation maps for public use, together with the relatively short lead time of flood forecasts, has constrained the effectiveness of non-structural measures in mitigating flood damages in Pakistan.

### B. *Categorization of Floods*

The Floods in Pakistan are classified into five categories, low, medium, high, very high, and exceptional, based on peak discharge magnitude. The discharge thresholds corresponding to these flood categories at major barrages and hydraulic control points are also presented in Fig. 5. Colored bars illustrate the discharge ranges corresponding to six flood categories, whereas black diamonds denote the station design capacity. These flood category thresholds are compared with the design discharge capacities of the respective hydraulic structures. The threshold values presented in Figure 5 are used to classify flood severity whenever the observed discharge at a control point exceeds the corresponding critical discharge limit.

Decisions related to flood regulation through dams, barrages, and other hydraulic control structures are made based on the integrated hydrological conditions across the entire river system. Moreover, the flood category at each control point is evaluated against the corresponding design discharge capacity to assess the hydraulic safety and operational performance of these structures during high flow events.

Such evaluations are essential for evaluating flood preparedness under climate change driven scenarios, in which extreme rainfall events combined with accelerated snow and glacier melt may generate inflows approaching or exceeding the design capacities of existing hydraulic infrastructure. Under such conditions, uncertainties in upstream inflow forecasting may further increase the probability of exceeding critical flood thresholds [41].

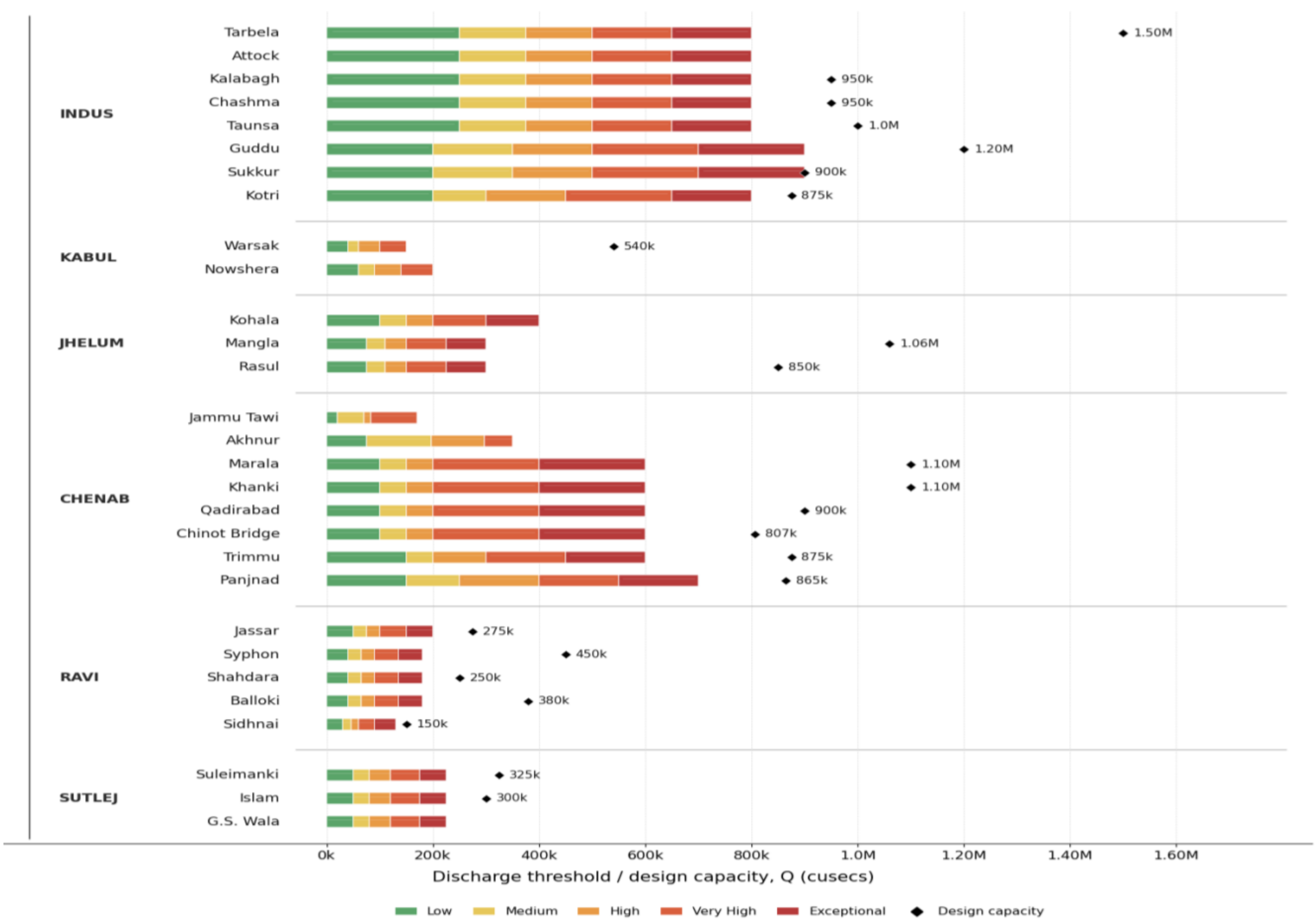


Fig. 5. Official flood threshold classification and design discharge capacity of major gauging stations in Pakistan as per Pakistan Meteorological Department (PMD). Values are expressed as discharge (Q) in cusecs and grouped by river basin. K = thousand cusecs; M = million cusecs.

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The design discharge capacities of the major hydraulic control points indicate that the Indus River possesses the highest flow conveyance capacity among the major rivers of Pakistan, followed by the Chenab and Jhelum rivers. The discharge thresholds defining the very high and exceptional flood categories generally increase progressively from the upstream northern reaches toward the downstream floodplains as the river enters the relatively flatter terrain of Sindh. These thresholds attain their maximum values at Guddu and Sukkur barrages before decreasing slightly further downstream at Kotri Barrage (Figure 5).

*C. Historical Analysis of Riverine Floods*

Figure 6 summarizes the historical occurrences of annual peak discharges recorded at major dams, barrages, and hydraulic control points using a heat map. Heat map is showing the annual maximum discharge (Q, cusecs) recorded at major gauging stations across the Indus River system and its principal tributaries. Cell colors indicate the corresponding flood threshold class derived from the Pakistan Meteorological Department (PMD) flood classification. Whereas, White cells denote years for which no official discharge record was available (NR). The figure points out the major flood years by illustrating the spatial and temporal distribution of flood magnitudes across the river network. It helps in rapid identification of years and monitoring locations associated with unusually high peak discharges based on the predefined flood category thresholds from figure 5. The dataset presented in Figure 6 covers the period since 1973 and includes all major hydraulic control points located along the principal rivers of Pakistan. Progressively lighter colors represent increasingly severe flood categories, thereby enabling the identification of hydrologically significant flood years affecting multiple river reaches simultaneously. In particular, yellow cells denote exceptional floods, whereas light green cells represent very high floods.

On the basis of available data, a total of 3, 1, and 3 flood years were identified during the 1970s, 1980s, and 1990s, respectively. In contrast, all years between 2010 and 2024 are represented as flood years in the heat map. Historically, severe flood events occurred between 1970 and 2000. In recent years, however, the frequency of flood occurrences appears to have increased, although most events have been characterized by comparatively lower peak magnitudes (Figure 6). Furthermore, flood occurrences in the Ravi and Sutlej rivers have declined considerably in recent years, except during the 2022 flood event, when the Sutlej River experienced a very high flood. In contrast, monitoring stations along the Indus, Jhelum, and Chenab rivers have recorded more frequent flood events in recent years, although most have remained within relatively moderate flood categories (Figure 6).

The maximum inflow and discharge recorded at major control points on the rivers for the recent flood of 2020 is given as Figure 7a. Blue bars represent in the graph shows PMD/FFD maximum seasonal inflow or observed flood peak, while orange bars show FFC maximum outflow or reported discharge. River stations are grouped in this figure as per major river system. “NR” indicates that the corresponding value was not separately reported in the consulted official source and should not be interpreted as zero flow. Moreover, the maximum inflow and maximum outflow represent independently reported seasonal maxima and are not necessarily simultaneous observations. This figure, to some extent, also represents the impact of regulation structure on subsiding flood peaks as per their storage capacity. The historical maximum flood discharges from the major monitoring stations are presented in Figure 7b. The figure compares the maximum recorded peak discharges at monitoring stations on the major rivers, grouped according to their respective river systems, thereby providing insight into the spatial distribution and temporal occurrence of historical flood extremes. The analysis of Figure 7b reveals that the year of occurrence of the historical maximum flood varies not only among control points along the same river but also among different river systems. Consequently, the historical maximum flood did not occur simultaneously across the major rivers of Pakistan.

For example, the historical maximum flood on the Indus River at Tarbela occurred in 2010, whereas the highest recorded flood on the Kabul River at Nowshera occurred in 2022. Similarly, the maximum flood recorded on the Jhelum River at Mangla and the Chenab River at Marala occurred in 1992 and 2011, respectively. Eastern rivers also show different historical flood years, with the maximum flood on the Ravi River at Jassar occurring in 1973, while the Sutlej River at Sulemanki experienced its historical maximum flood in 1988. These observations show historical maximum flood peaks have occurred independently across different river systems that explains the distinct hydrological and meteorological characteristics of their respective catchments.

As per Figure 7 b, among the upstream monitoring stations, the highest historical peak discharge was recorded on the Jhelum River at Mangla, with a peak discharge of 1.09 million cusecs, followed by the Chenab River at Marala, with a peak discharge of 0.969 million cusecs. Although the Indus River is the largest river in Pakistan in terms of average discharge, maximum recorded peak discharge from Tarbela was 0.604 million cusecs. However, as the Indus River flows downstream, it receives considerable inflows from its major offshoots at successive unions, as illustrated in Figure 4, which result in progressive development of flood peaks. Consequently, the historical maximum peak discharge from Guddu Barrage reached approximately 1.2 million cusecs, primarily because of the cumulative contributions from the tributaries of the Indus River. This downstream amplification of flood peaks increases the flood vulnerability of specific river reaches. In particular, the Chashma-Taunsa, Taunsa-Guddu, and Guddu-Sukkur reaches of the Indus River, as well as the Marala-Rasul reach of the Jhelum River, have historically exhibited a comparatively higher susceptibility to severe flooding.

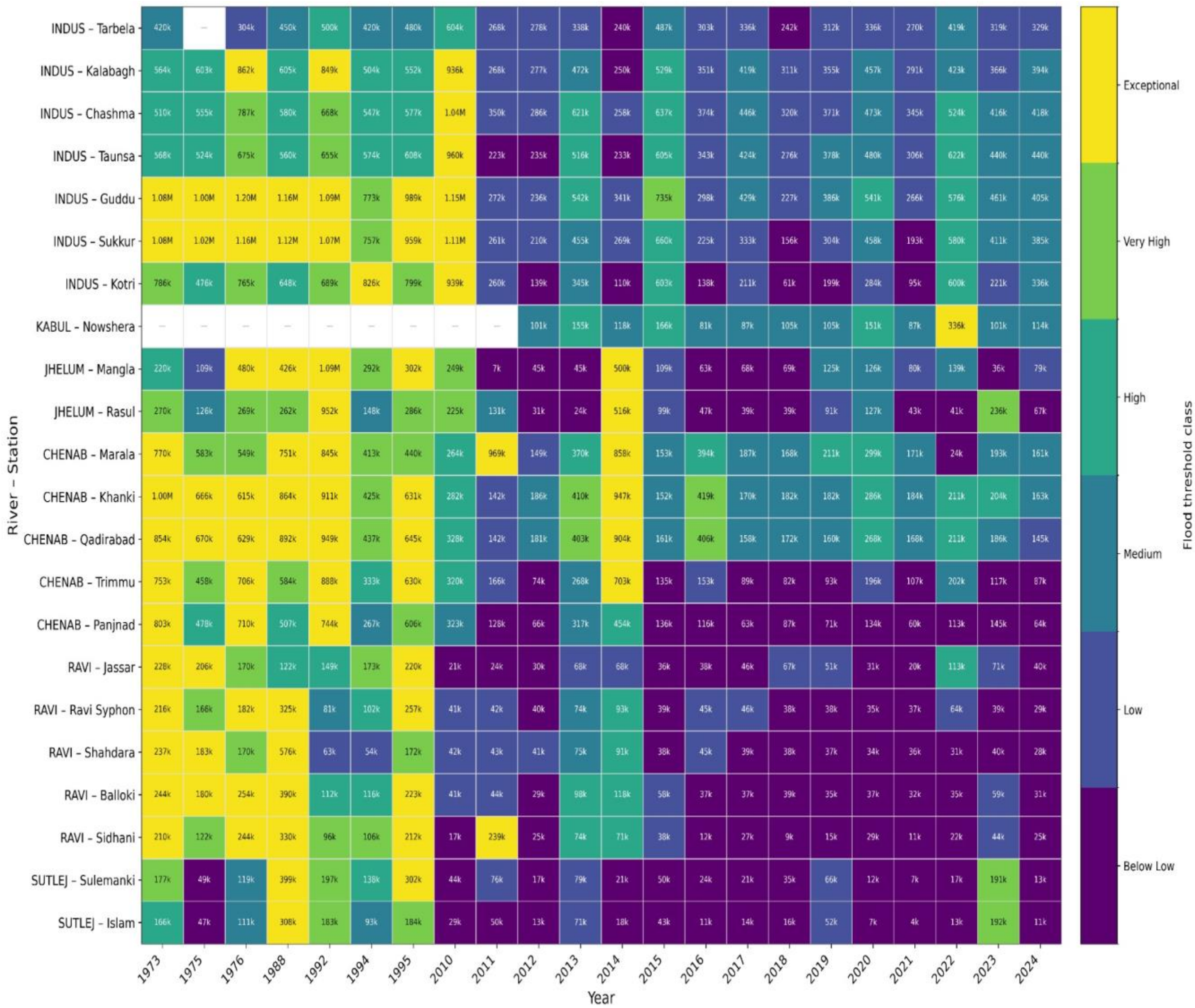


Fig. 6. Historical annual peak discharge at major river gauging stations in Pakistan (1973-2024). (Q = peak discharge (cusecs), M = million cusecs, K = thousand cusecs.)

### D. Historical Analysis of Various Categories of Floods

Although floods have affected different regions of Pakistan almost every year during the past decade, their nature, type, and geographical distribution have varied considerably from year to year. The historical occurrence of different flood types is presented in Figure 8. Based on the proposed classification framework, 13 distinct flood types have been reported in Pakistan. Considering flood classification based on water source and physical origin, all four major flood types, riverine, cryospheric, pluvial, and coastal flooding, have been reported throughout the study period. Riverine flooding has remained the most persistent flood type in Pakistan, followed by cryospheric flooding (Figure 8), the frequency of which has increased in recent years because of accelerated snowmelt and glacier melt [54], [55], [32], [56].

Riverine flooding is triggered by multiple hydrometeorological processes, including intense monsoon rainfall, cloudburst events within river catchments, seasonal snowmelt, glacier melt, and Glacial Lake Outburst Floods (GLOFs) that contribute additional runoff to the river system. Depending on the prevailing hydrological conditions, one or more of these processes may act simultaneously to generate riverine flooding. The resulting runoff generated within the catchments is conveyed through the main stems of the Indus, Jhelum, Chenab, Kabul, and occasionally the Ravi and Sutlej rivers, ultimately producing widespread riverine flooding across the floodplains of Punjab and northern Sindh, which are reported in [43], [44], [45], [46], [47], [48], [49], [50], [51], [52], [53].

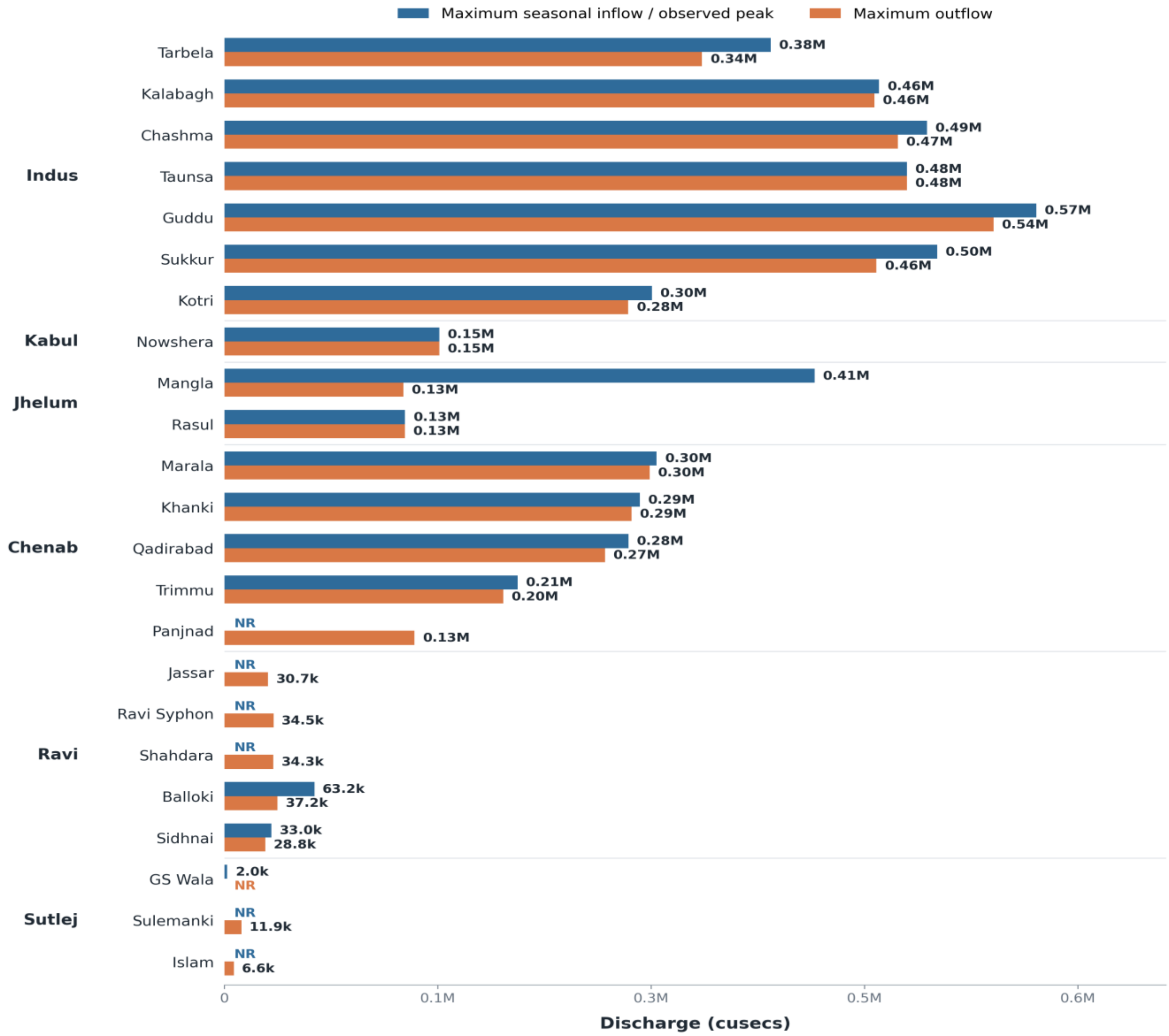


Figure 7a Station wise comparison of maximum seasonal observed inflow and reported peak discharge during the 2020 flood season.

As shown in Figure 8, Pluvial flooding has also become increasingly frequent during the present century, particularly in Sindh and Balochistan [57], [24], [58], [36], [51], [52]. In contrast, coastal flooding has remained relatively infrequent and has been reported only during a limited number of years [59].

Considering flood classification based on geographical and environmental setting, rural flooding affecting agricultural lands has remained a recurring phenomenon throughout the past 74 years, particularly across the low lying floodplains of Punjab and northern Sindh [13], [36], [49], [52], [65], [66], [68], [70], [71] as shown in Figure 8. These flood are mainly caused by overbank flow from the major rivers. Likewise, mountainous and valley floods have occurred intermittently as a consequence of rapid runoff generation within steep mountainous catchments. However, their frequency appears to have increased in recent years [36], [68], [72], [73], [40], [74], [75] [66]. [47], possibly because of more intense rainfall events and/or accelerated snowmelt

Urban flooding has emerged as an increasingly significant hazard in recent decades. Major cities, including Karachi, Lahore, Rawalpindi, and Peshawar, have experienced intense summer rainfall events that frequently result in urban flooding [13], [49], [60], [61], [24], [39]. [62]. [63]. [64]. [65]. [66] [67]. This trend is attributed to the combined effects of rapid urbanization, increasing impervious surface coverage, inadequate storm water drainage capacity, and the expansion of high density urban development. The progressive reduction in pervious surfaces has limited rainfall infiltration rate. Consequently, prolong surface water ponding occurs even after rainfall has ceased. Moreover, increasing population has forced additional hydraulic loading on the combined sewerage and drainage systems which is reducing the available capacity for storm water conveyance. The combined influence of these factors, together with increasingly intense rainfall events, has substantially increased the occurrence and severity of urban flooding in major cities across Pakistan.

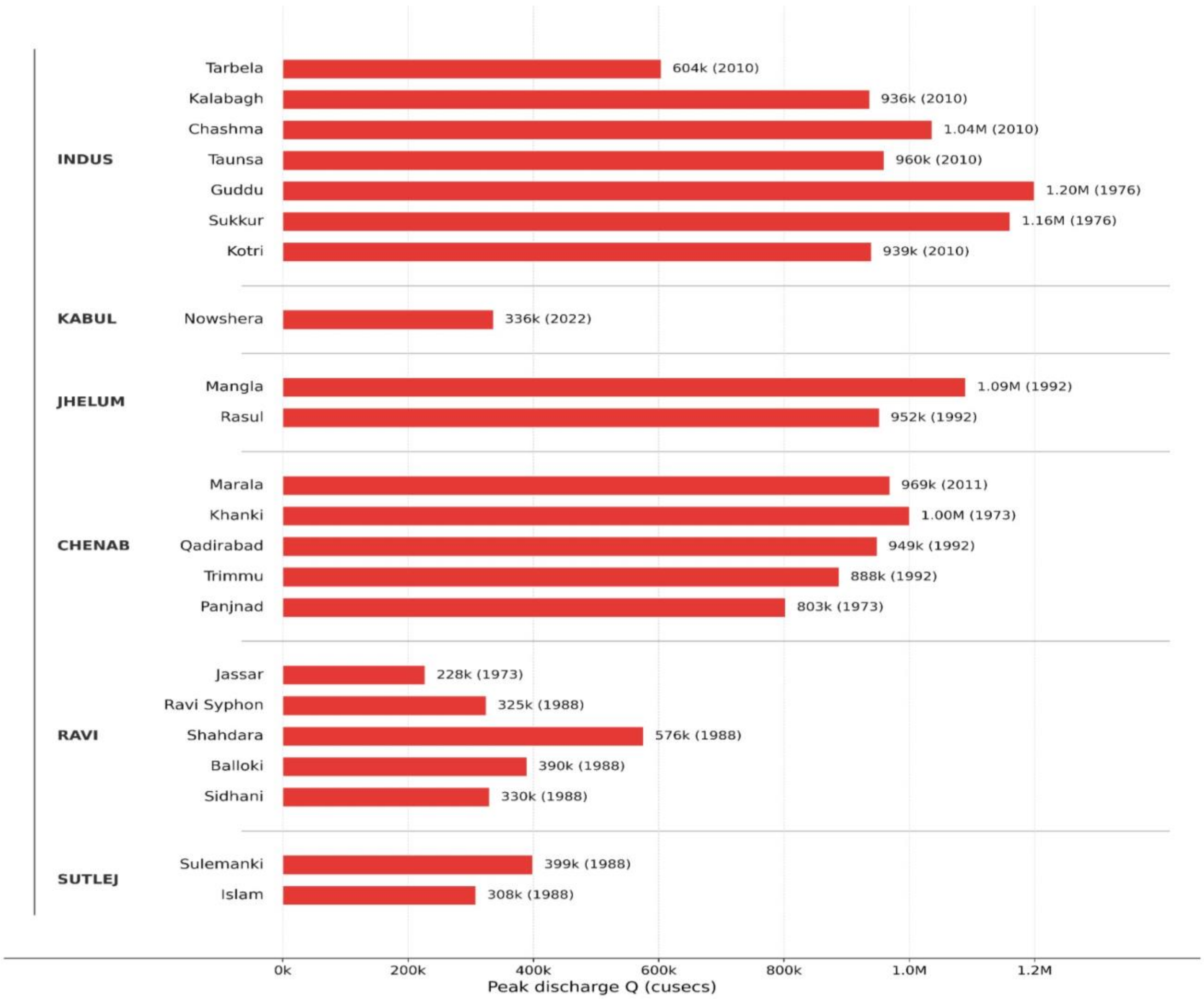


Fig. 7b. Historical peak discharge recorded at major river gauging stations in Pakistan. Horizontal bars represent the highest recorded peak discharge (Q, cusecs) at each gauging station, while labels at the end of each bar indicate the discharge magnitude and the corresponding year of occurrence. Stations are grouped according to their respective river basins to facilitate comparison of historical flood magnitudes. Q = discharge (cusecs); k = thousand cusecs; M = million cusecs.

When classified according to flood onset characteristics, all three categories, flash floods, slow onset floods, and cloudburst floods, have become increasingly frequent in recent decades. Rainfall produces different hydrological responses depending on regional physiography. Intense rainfall over steep mountainous terrain generates flash floods in Khyber Pakhtunkhwa (KP), Gilgit-Baltistan (GB), and the Koh-e-Suleiman mountain range, whereas widespread catchment-scale rainfall produces slow onset flooding across the plains of Punjab and Sindh. Flood waves in the Indus River and its tributaries require several days to propagate downstream before inundating the lower floodplains through overbank flow. Historical records indicate that the frequency of slow onset floods has also increased during the past two decades [82], [33], [83], [84], [85].

Flash flood events predominantly affected Khyber Pakhtunkhwa (KP), Gilgit-Baltistan (GB), Southern Punjab, and Azad Jammu and Kashmir (AJK) [68], [76], [47], [77], [37], [78], [66], [79], [80], [81]. The Koh-e-Suleiman mountain range contains numerous hill torrents that frequently generate destructive flash floods in the Dera Ghazi Khan and Rajanpur districts following intense rainfall events. Flash floods are generally triggered by high-intensity rainfall associated with convective storms or other localized meteorological events and have become an increasingly recurrent phenomenon in recent years. Similarly, cloudburst events have been reported intermittently during the past decade as highly localized, high-intensity rainfall events [86], [38], [87], [88].

Since 2019, GLOFs have been reported in six consecutive years [65], [74], [75]. Glacial Lake Outburst Floods (GLOFs) have predominantly occurred in Gilgit-Baltistan (GB) and the northern districts of Khyber Pakhtunkhwa (KP). Accelerated glacier melting associated with global warming has increased the occurrence of unstable glacial lakes, resulting in more frequent GLOF events in recent years. Flooding associated with the breach or failure of hydraulic infrastructure, including canals, barrages, levees, and flood embankments, has also been documented repeatedly over the past decades [49], [65], [89], [90], [91], [92], [93], [94]. Likewise, several cases of localized backwater flooding caused by ice accumulation, debris, and sediment jams obstructing flow in northern mountain streams have been reported in recent years [95], [96], [97], [56].

The years 2010, 2020, and 2022 witnessed an unusual combination of multiple flood types affecting different regions of Pakistan simultaneously (Figure 8). In particular, the 2022 flood event represents an exceptional example of compound flooding, during which GLOFs affected the northern mountainous regions of Gilgit-Baltistan and Khyber Pakhtunkhwa, riverine flooding inundated the floodplains of Punjab and Sindh, hill torrents generated destructive flooding in Dera Ghazi Khan and Rajanpur, urban flooding affected Karachi and other major cities, and the failure or breaching of several hydraulic structures occurred in Balochistan. Unlike previous historical events, during which different types of flood occurred independently or with different severity, in the flood of 2022 nearly all major flood types occurred simultaneous across the country. This compound flooding event indicates a potential shift in both the spatial distribution and the hydrological behavior of flooding in Pakistan.

The historical occurrence of the reported Pakistan flood types is summarized in Figure 8. This illustrates the progressive evolution of different flood types throughout the study period. Riverine flood has remained consistently reported flood type across Pakistan, except during a few recent years when other flood types became increasingly prominent. In most years, riverine flooding has also been the principal cause of rural and agricultural flooding. Pluvial and cryospheric floods, represent next most frequently reported flood categories with respect to source, primarily resulting from intense rainfall and snowmelt/glacier melt processes, respectively.

Considering place of occurrence, rural / agricultural floods occurred regularly, however urban flooding and flash floods became increasingly frequent during the period 2001-2025. The reporting of floods with respect to onset speed has been found a recent phenomenon in the literature. Since, 2000 many floods have been reported in the categories of flash, slown-onset and cloudburst floods. Especially, the cloudburst has been reported more frequently in last five years. Similarly, either the frequency of GLOF, infrastructure failure and ice-jam floods is actually increasing or these have observed and reported more often since 2010. The combine occurrence of multiple flood types produced compound flooding during 2010, 2020, and 2022. Furthermore, available historical records indicate that GLOFs, Infrastructure failure floods, ice-jam floods, cloud outburst floods were either absent or extremely limited during the previous century. In contrast, during the past decade, GLOFs and urban flooding have been reported almost every year, this suggests a shift in the flood regime of Pakistan that may be associated with climate change and increasing anthropogenic influences.

### *E. Impact of Climate Change on Flooding in Pakistan*

Climate change has reportedly changed the annual mean temperature, precipitation patterns, along with glacier melt dynamics in Pakistan. Each factor significantly impacts flood timing, peak discharge, inundation extent, flood duration, and the frequency of flood occurrence.

#### *1) Mean Annual temperature rise impact on flooding*

During the past six decades, the mean annual temperature in Pakistan has increased at an average rate of approximately 0.186°C per decade. This pattern indicates a progressive warming of the country's climate, with a more pronounced increase observed since 1990. Rising temperatures contribute to accelerated glacier melt and increase the atmospheric moisture holding capacity. According to the IPCC, the atmosphere can hold approximately 7% more moisture for every 1°C increase in temperature, thereby increasing the potential for more intense precipitation events. Collectively, these processes are expected to increase flood risk in Pakistan [98].

#### *2) Changing Rainfall Pattern in Pakistan*

Long term statistical analyses of annual rainfall records indicate an increasing trend in precipitation across Pakistan, with an average increase of approximately 11 mm per decade. Increased monsoon rainfall has been reported across the northern regions of Pakistan, including Gilgit, Skardu, Chilas, Islamabad, and Peshawar. Because monsoon precipitation is the primary driver of riverine flooding in Pakistan, these changing climatic conditions are expected to increase the likelihood of future flood events affecting downstream communities [98]. Furthermore, previous studies have reported an increase in rainfall frequency across many parts of Pakistan, with daily precipitation intensities increasing by approximately 30 mm day$^{-1}$ [98]. Although increased rainfall during the dry season may have a limited influence on flood generation, the intensification of rainfall during the monsoon season is likely to substantially increase flood magnitude. Therefore, the relationship between changing rainfall patterns and flood occurrence warrants further investigation [98].

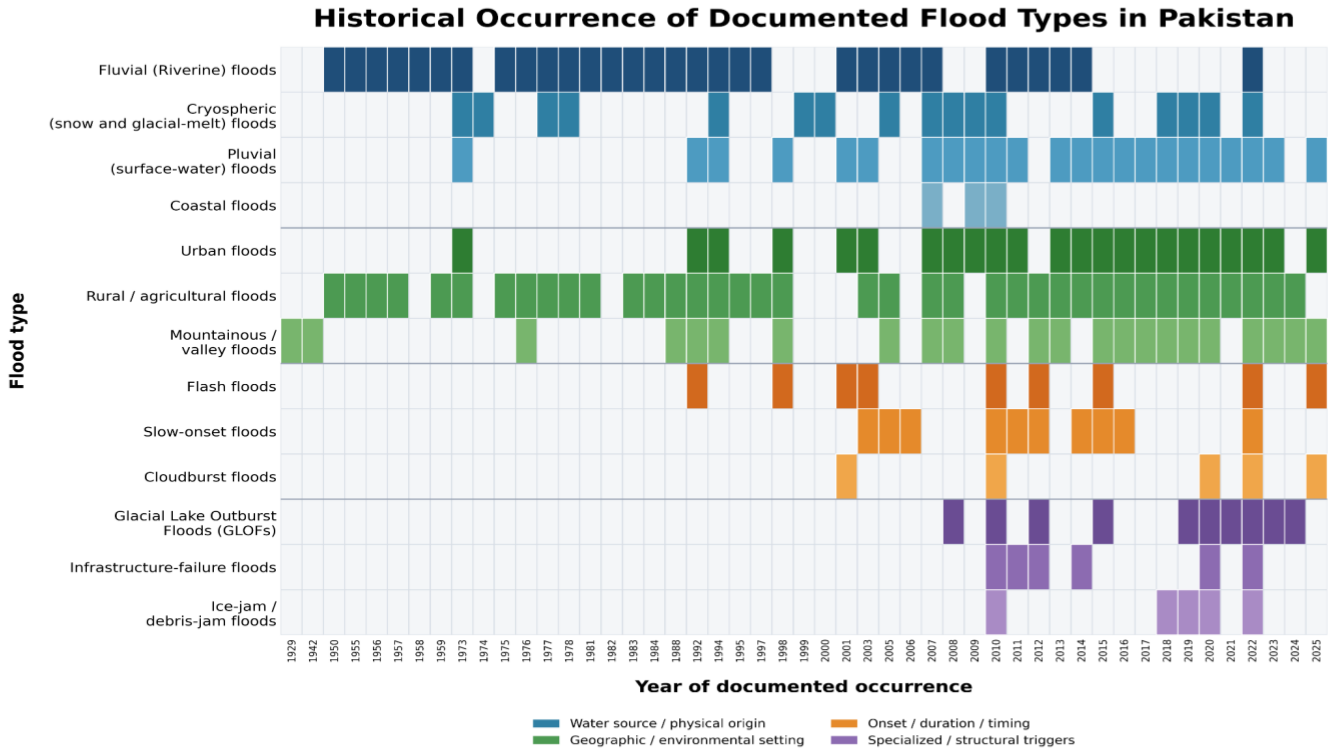


Fig. 8. Historical occurrence of documented various types of floods. Filled cells in the graph indicates year in which a flood type was documented in the compiled official reports and literature. Empty cells show that the corresponding flood type was not documented in the reviewed sources for that year. Further, it should not be deduced as proof of nonoccurrence. Flood types were classified as per types defined in Figure 1.

*3) Changing Glacial Melt Pattern in Pakistan*

Accelerated glacier melt, declining snowfall, and rising temperatures are altering the hydrological regime of glacier-fed river systems in Pakistan. A reduction in snowfall days has been reported in several northern mountainous regions, including Chitral, Murree, Skardu, and Parachinar, resulting in reduced seasonal snow accumulation. Increasing temperatures, combined with declining snowfall, are expected to accelerate glacier melting and increase the occurrence of Glacial Lake Outburst Floods (GLOFs) through the formation and destabilization of glacial lakes. These processes are likely to increase meltwater contributions to river flows and consequently augment flood runoff during extreme hydrological events [98].

### F. Impact of Anthropogenic Activities on Flooding in Pakistan

In addition to climate change, anthropogenic activities have significantly influenced flood characteristics and the associated damages in Pakistan. Understanding these anthropogenic influences is helpful for evaluating the evolving dynamics of flooding, especially in densely populated countries. Due to rapid population, there has been increase in demand for residential areas and infrastructure. This resulted in accelerated urbanization, at the expense of natural ecosystems. Expanding developmental activities, like construction of urban settlements, and other engineering works within river catchments, have contributed to deforestation and degradation of natural landscapes. These activities have substantially altered the hydrological response of catchments to rainfall by reducing infiltration, increasing surface runoff, shortening the time to peak discharge, and consequently increasing flood susceptibility.

Similarly, increasing population density has substantially expanded the proportion of impervious surfaces in all major cities of Pakistan [99]. Existing urban drainage systems, which were originally designed for considerably smaller populations and lower levels of urbanization, no longer possess adequate hydraulic capacity to convey the increased stormwater runoff. The progressive reduction in permeable surfaces has further limited natural infiltration, while increased domestic water consumption has imposed additional hydraulic loading on urban drainage networks. Moreover, the rapid vertical expansion of major urban centers has significantly increased stormwater drainage requirements. The inability of urban drainage infrastructure to expand with respect to increasing demand has resulted in growing occurrence of urban flooding in recent years [39].

### G. Historical Flood Damages in Pakistan Since 1950

Although flooding has provided localized benefits in certain regions, such as groundwater recharge [100], its adverse impacts substantially outweigh these benefits, particularly in densely populated countries with limited flood risk management capacity. Figure 9 presents the historical flood damages at the national scale in Pakistan for the period 1950-

2024, compiled from the Federal Flood Commission (FFC) Annual Flood Reports [42].

Flood damages are multidimensional; however, Figure 9 presents four principal damage indicators: human fatalities, inundated area, affected villages, and economic losses. Because these variables differ considerably in magnitude and units, the heat map uses a graduated color scale ranging from light to dark shades, where darker shades represent more severe flood impacts.

During the period 1950-2024, the 1950 flood was the deadliest event in terms of human fatalities, with more than 2,000 reported deaths. Approximately six decades later, the 2010 flood recorded nearly 2,000 fatalities, while the 2022 flood became the third deadliest event, resulting in more than 1,700 fatalities. The 1992 flood also caused approximately 1,000 deaths. Further, several flood events caused loss of hundreds of human lives, demonstrating the persistent severity of flood hazards in Pakistan.

With respect to inundation, the 2010 flood was the most widespread, affecting approximately 160,000 km², followed by the 2022 flood, during which 85000 Km$^2$ of land was flooded.

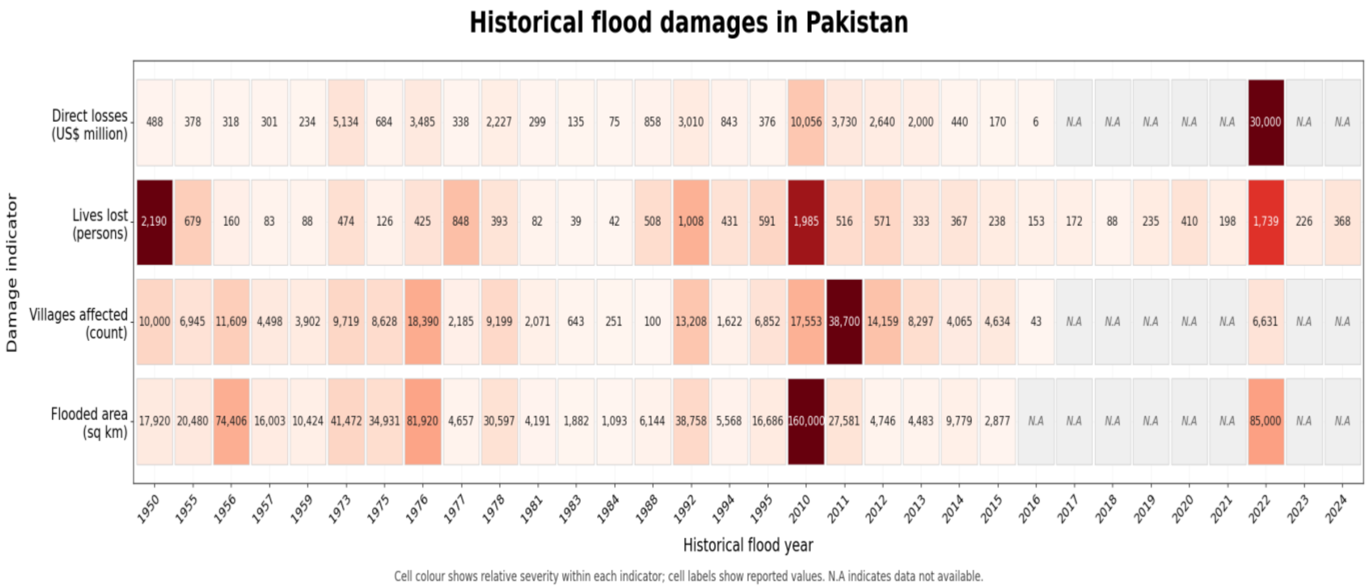


Fig. 9. Historical Flood Damages in Pakistan Since 1950. Historical flood damages associated with major flood events in Pakistan (1950-2024) from Federal Flood Commission (FFC) report. Cell annotations indicate the reported values for each flood year, while color intensity represents the relative magnitude within each indicator (darker shades indicate greater impacts). N.A. denotes years for which official data were unavailable.

Where data were unavailable or not reported, the corresponding entries are denoted as N.A, indicating gaps in the available historical records rather than the absence of flood impacts. Although the extent of inundation generally increases with flood magnitude, every major flood event inundated thousands of acres of land. Interestingly, the 2011 flood affected the highest number of villages, despite being relatively moderate with respect to inundated area, human fatalities, and economic losses. It is noteworthy that the number of affected villages exhibits a general correlation with flood severity during certain flood years (e.g, 1976, 1978, and 1992), however, this relationship is not consistently proportional to the total inundated area. The number of affected villages depends not only on flood magnitude but also on the geographical distribution, spatial extent, and nature of the flood event. The highest recorded economic loss occurred during the 2022 flood, with an estimated financial damage of approximately US$30 billion, followed by approximately US$10 billion during the 2010 flood.

*H. Recent Flood Damages in Pakistan*

A comprehensive summary of the damages associated with recent flood events is presented in Figure 10. The figure includes nine major damage indicators: human fatalities, injured persons, damaged houses, affected villages, affected population, inundated area, damaged roads, damaged bridges, and livestock losses. Overall, the 2022 flood was the most devastating event during the study period, followed by the 2010 and 2011 floods. The 2022 flood affected more than 33 million people, caused the loss of approximately 1.16 million livestock, and damaged approximately 2.29 million houses. Comparable categories of damage were also reported during the 2010 and 2011 flood events, although with relatively lower severity, as illustrated in Figure 10. Furthermore, since 2010, every recorded flood year has resulted in human fatalities, highlighting the persistent vulnerability of Pakistan to flood related disasters.

| | Deaths | Injured | Houses Damaged | Villages Affected | People Affected | Cropped Area (ha) | Cropped Area (acres) | Roads / Road Bridges | Bridges | Livestock / Cattle |
|---|---|---|---|---|---|---|---|---|---|---|
| 2010 | 1,985 | 2,946 | 1.61M | 17.6k | 20.18M | 2.09M | N.A | 25.1k | N.A | N.A |
| 2011 | 516 | 770 | 1.60M | 38.7k | 9.30M | N.A | 2.31M | N.A | N.A | 118k |
| 2012 | 571 | 2,907 | 820k | 14.2k | 4.85M | N.A | 1.17M | N.A | N.A | 12.1k |
| 2013 | 333 | 173 | 79.9k | 8,297 | 1.49M | N.A | 1.11M | N.A | N.A | 13.5k |
| 2014 | 367 | 673 | 107k | 4,065 | 2.60M | N.A | 2.42M | N.A | N.A | 9,722 |
| 2015 | 238 | 232 | 10.7k | 4,634 | 1.93M | N.A | N.A | N.A | N.A | N.A |
| 2016 | 153 | 113 | 1,452 | 45 | N.A | N.A | N.A | N.A | N.A | 194 |
| 2017 | 172 | 167 | 440 | N.A | N.A | N.A | N.A | N.A | N.A | N.A |
| 2018 | 88 | 158 | 362 | N.A | N.A | N.A | N.A | N.A | N.A | N.A |
| 2019 | 235 | 169 | 272 | N.A | N.A | N.A | N.A | N.A | N.A | N.A |
| 2020 | 410 | 400 | 135k | N.A | N.A | N.A | N.A | 41 | N.A | N.A |
| 2021 | 198 | 299 | 836 | N.A | N.A | N.A | N.A | 22 | N.A | N.A |
| 2022 | 1,739 | 12.9k | 2.29M | N.A | 33.05M | N.A | N.A | 13.1k | 439 | 1.16M |
| 2023 | 226 | 349 | 5,813 | N.A | N.A | N.A | N.A | 23.92 | 5 | 1,260 |
| 2024 | 368 | 668 | 58.2k | N.A | N.A | N.A | N.A | 501.49 | 42 | 2,283 |

Fig. 10. shows the province wise distribution of national flood mortality recorded in Pakistan from 2010 to 2024. Color intensity indicates the relative magnitude within each indicator, with darker shades representing greater impacts. M = million; k = thousand; ha = hectares; N.A. = data not available in official reports.

The province- and region-wise flood-related mortalities during the period 2010-2024 are presented in Figure 11. The heat map provides a comparative visualization of flood-related fatalities across the provinces and administrative regions of Pakistan. In the annual dataset, the mortality records for the Federally Administered Tribal Areas (FATA) and Khyber Pakhtunkhwa (KP) are reported separately up to 2018, after which FATA was administratively merged with KP, and the data are reported accordingly. Similarly, the mortality data for the Islamabad Capital Territory (ICT) are presented separately up to 2018 and subsequently merged with Punjab in the following years to maintain consistency with the available official records.

The compiled data indicate that all provinces and regions have experienced distinct mortality patterns because of differences in flood type, population density, settlement exposure, topography, flood warning lead time, disaster preparedness, emergency response capability, and evacuation capacity. Khyber Pakhtunkhwa (KP) has recorded the highest number of flood-related fatalities, followed by Punjab and Sindh. The relatively higher mortality in KP is primarily attributed to the presence of numerous districts within mountainous catchments that are highly susceptible to flash floods, Glacial Lake Outburst Floods (GLOFs), and riverine flooding. Additionally, Peshawar has become increasingly vulnerable to urban flooding. In Punjab, fatalities related to flood have mainly resulted from riverine, torrential, and urban flooding. Although Sindh generally experienced comparatively fewer fatalities during most flood events, the 2022 flood resulted in an exceptionally high mortality, with nearly 800 reported deaths. In comparison, relatively lower flood mortalities have been reported from Balochistan, Gilgit Baltistan (GB), and Azad Jammu and Kashmir (AJK) throughout the study period [42], [49], [89], [90], [91], [92], [101], [102], [103], [104], [105], [106], [107], [108], [109]

This preliminary research is constrained by: 1) the investigations were performed on a limited data set available through public reports from FFC, PMD, NDMA and reported research papers leaving the possibility of non-reporting the floods whose data was not available as well as interpretation errors about the flood types, etc. 2) The possibility of data errors could in the source reports could be carried towards this study

Therefore, future investigations should involve more extensive data set by requiring the data directly from the data recording organizations.

*I. Uncertainty associated with historical flood records*

Pakistan historical flood records contain innate uncertainty because different agencies observation differ based on time period, station networks and different hydrological terminologies. Uncertainty may arise due to many reasons, for example Kabul River flow at Nowshera exceeded 350,000 cusecs and that the measuring gauge was believed to have been overtopped, so the actual flow was not fully reported. PMD/FFD reports provide observed flood peaks and seasonal peak summaries, whereas FFC/PIDs/WAPDA/IRSA records provide historical discharge, design capacity of stations, and classification of flood data. Therefore, these datasets are complementary but not fully integrated and interchangeable. Missing values were therefore marked as "NR" and were not treated as zero.

**Province-wise lives lost due to floods in Pakistan (2010–2024)**

| | Punjab | Sindh | KP | Baloch. | FATA | GB | AJK | ICT | Punjab+ICT | KP+MA |
|---|---|---|---|---|---|---|---|---|---|---|
| 2010 | 110 | 411 | 1,156 | 54 | N.A | 183 | 71 | N.A | N.A | N.A |
| 2011 | 4 | 497 | 0 | 0 | 3 | 0 | 12 | N.A | N.A | N.A |
| 2012 | 63 | 283 | 38 | 156 | N.A | N.A | 31 | N.A | N.A | N.A |
| 2013 | 109 | 47 | 70 | 39 | 35 | N.A | 33 | N.A | N.A | N.A |
| 2014 | 286 | N.A | 12 | N.A | N.A | 13 | 56 | N.A | N.A | N.A |
| 2015 | 58 | 0 | 109 | 16 | 19 | 10 | 26 | N.A | N.A | N.A |
| 2016 | 29 | N.A | 69 | 18 | 27 | 3 | 6 | 1 | N.A | N.A |
| 2017 | 38 | 38 | 28 | 26 | 18 | 8 | 13 | 3 | N.A | N.A |
| 2018 | 31 | N.A | 22 | 1 | 9 | 4 | 21 | N.A | N.A | N.A |
| 2019 | N.A | 63 | N.A | 12 | N.A | 8 | 42 | N.A | 32 | 78 |
| 2020 | N.A | 145 | N.A | 21 | N.A | 12 | 12 | N.A | 104 | 116 |
| 2021 | N.A | 15 | N.A | 24 | N.A | 6 | 9 | N.A | 55 | 89 |
| 2022 | N.A | 799 | N.A | 336 | N.A | 23 | 48 | N.A | 224 | 309 |
| 2023 | N.A | 27 | N.A | 21 | N.A | 7 | 18 | N.A | 85 | 68 |
| 2024 | N.A | 77 | N.A | 42 | N.A | 4 | 10 | N.A | 123 | 112 |

Fig. 11. Shows the province and region wise distribution of flood mortality recorded in Pakistan from 2010 to 2024. Heat map shows reported number of deaths due to floods across Pakistan's provinces and administrative regions. Cell annotations indicate the reported fatalities for each year, while color intensity represents the relative mortality within each province year combination (darker shades indicate higher fatalities). KP = Khyber Pakhtunkhwa; Baloch. = Balochistan; FATA = Federally Administered Tribal Areas; GB = Gilgit–Baltistan; AJK = Azad Jammu and Kashmir; ICT = Islamabad Capital Territory MA = Merged Areas; N.A. = data not reported.

## IV. Conclusions and Recommendations

1. Floods have affected different regions of Pakistan intermittently since 1950; however, their frequency has increased noticeably since 2010, most likely because of the combined influence of climate change and anthropogenic activities.

2. A total of 13 flood types have been identified in Pakistan over the past 75 years, based on four classification criteria: water source and physical origin (riverine, cryospheric, pluvial, and coastal), geographical setting (urban, rural, and mountainous/valley), onset characteristics (flash, slow-onset, and cloudburst), and special triggering mechanisms (Glacial Lake Outburst Floods (GLOFs), infrastructure failure floods, and ice-jam/debris-jam floods). Among these, riverine and cryospheric floods represent the traditional flood types with a long history of regular occurrence, whereas the occurrence GLOFs, ice-jam/debris-jam floods, and urban flooding has increased markedly in recent years.
3. Pakistan has established an flood regulation and monitoring network comprising major reservoirs, barrages, and hydraulic control structures along the Indus, Jhelum, Chenab, Kabul, Ravi, and Sutlej rivers. These hydraulic structures not only assist in the attenuation of flood peak to the extent of their regulatory capacity but also function as discharge monitoring stations, where peak discharges are classified into five operational flood categories, low, medium, high, very high, and exceptional.
4. Historical records show severe flood events from 1970 and 2000, In contrast, recent decades have experienced more frequent flood events, although most have exhibited comparatively lower peak magnitudes.
5. Historical maximum peak discharges recorded at the main hydraulic control points shows that the maximum flood peak did not occur simultaneously across all river systems. This reflects the distinct hydrological characteristics of individual river catchments. The highest peak discharge was recorded from the Jhelum River at Mangla, reaching 1.09 million cusecs in 1992, followed by the Chenab River at Marala, with 0.969 million cusecs in 2011. Although the Indus River is the largest river in Pakistan in terms of average discharge, the maximum recorded peak discharge from Tarbela was 0.604 million cusecs in 2010.
6. The historical analysis indicates that certain river reaches are prone to severe flooding than others. In particular, the Taunsa-Guddu and Guddu-Sukkur reaches of the Indus River, the Mangla-Rasul reach of the Jhelum River, and the Marala-Khanki and Khanki-Qadirabad reaches of the Chenab River have historically experienced comparatively higher flood discharges.
7. Temporal analysis of various flood occurrences indicates that riverine, rural floods and mountainous /valley floods were the dominant flood types during the period 1950-2010. In contrast, Urban flooding, Glacial Lake Outburst Floods (GLOFs), Pluvial and Flash floods have become increasingly frequent during 2010-2025, possibly under the impact of climate change. The simultaneous occurrence of multiple flood types resulted in pronounced compound flooding during 2010, 2020, and 2022. Furthermore, reports of GLOFs, Cloudburst, Infrastructure failure Floods and Debri-jam Flooding were either not found or rarely reported in previous century, whereas these flood types have been reported frequently during the past decade, indicating a shift in the flood regime of Pakistan.
8. Total four parameters of long-term available record (1950-2024) of flood damages are chosen to analyze the flood damage including human live lost, inundated area, villages effected and financial loss. Since 1950 till 2024, the flood of 1950, 2010, 2022 and 1992 were found most lethal with respect to human live lost where casualties range between 1000-2000.
9. Recent flood damages during the period 2010-2024 were evaluated in greater detail by including affected population, injured persons, damaged houses, livestock losses, affected crop area, damaged roads, and damaged bridges (excluding variables for which data were unavailable). The analysis revealed that the flood of 2022, 2010, and 2011 were the most devastating during the study period. The 2022 flood alone affected more than 33 million people, caused the loss of approximately 1.16 million livestock, and damaged approximately 2.29 million houses, that highlight the need for further research in better flood management to reduce avoidable damages considering the impacts of increasing urbanization and climate change.
10. Shifting climate patterns necessitates the upgradations of flood forecasting models according to requirements of local environment, catchment characteristics, type of flooding and purpose of forecast. Specially, the focus should be on enhancing the forecast lead time.
11. The early warning systems could benefit from the extended lead time forecast, reducing the communication delay to the minimum and the readiness of the departments involved in relief and rescue operations.
12. Flood management process could leverage from the public availability of development / revisions of flood risk and vulnerability maps in order to minimize the avoidable damage.

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The authors declare no conflicts of interest to report regarding the present study.

AUTHOR CONTRIBUTIONS

Conceptualization, M.K.S; methodology, M.K.S. and M.W.H.R; software, M.W.H.R; validation, M.W.H.R; writing M.K.S. and M.W.H.R; writing review and editing, M.K.S.

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Data is available on reasonable request.

## REFERENCES

[1] B. Tellman *et al.*, "Satellite imaging reveals increased proportion of population exposed to floods," *Nature*, vol. 596, no. 7870, pp. 80–86, Aug. 2021, doi: 10.1038/s41586-021-03695-w.

[2] M. Shamsudduha, "Redefining flood hazard and addressing emerging risks in an era of extremes," *npj Nat. Hazards*, vol. 2, no. 1, p. 29, Apr. 2025, doi: 10.1038/s44304-025-00082-7.

[3] M. Salhab and J. Rentschler, *People in Harm's Way: Flood Exposure and Poverty in 189 Countries*. World Bank, Washington, DC, 2020. doi: 10.1596/1813-9450-9447.

[4] B. Jongman, P. J. Ward, and J. C. J. H. Aerts, "Global exposure to river and coastal flooding: Long term trends and changes," *Global Environmental Change*, vol. 22, no. 4, pp. 823–835, Oct. 2012, doi: 10.1016/j.gloenvcha.2012.07.004.

[5] J. Rentschler, M. Salhab, and B. A. Jafino, "Flood exposure and poverty in 188 countries," *Nat Commun*, vol. 13, no. 1, p. 3527, Jun. 2022, doi: 10.1038/s41467-022-30727-4.

[6] S. Seneviratne *et al.*, "Chapter 3 Changes in climate extremes and their impacts on the natural physical environment," 2012.

[7] Y. Hirabayashi *et al.*, "Global flood risk under climate change," *Nature Clim Change*, vol. 3, no. 9, pp. 816–821, Sep. 2013, doi: 10.1038/nclimate1911.

[8] H. Tabari, "Climate change impact on flood and extreme precipitation increases with water availability," *Sci Rep*, vol. 10, no. 1, p. 13768, Aug. 2020, doi: 10.1038/s41598-020-70816-2.

[9] A. Sharma, C. Wasko, and D. P. Lettenmaier, "If Precipitation Extremes Are Increasing, Why Aren't Floods?," *Water Resources Research*, vol. 54, no. 11, pp. 8545–8551, 2018, doi: 10.1029/2018WR023749.

[10] F. Dottori *et al.*, "Increased human and economic losses from river flooding with anthropogenic warming," *Nature Clim Change*, vol. 8, no. 9, pp. 781–786, Sep. 2018, doi: 10.1038/s41558-018-0257-z.

[11] Intergovernmental Panel On Climate Change (Ipcc), *Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, 1st ed. Cambridge University Press, 2023. doi: 10.1017/9781009157896.

[12] M. A. U. R. Tariq and N. van de Giesen, "Floods and flood management in Pakistan," *Physics and Chemistry of the Earth, Parts A/B/C*, vol. 47–48, pp. 11–20, Jan. 2012, doi: 10.1016/j.pce.2011.08.014.

[13] Z. Manzoor *et al.*, "Floods and flood management and its socio-economic impact on Pakistan: A review of the empirical literature," *Front. Environ. Sci.*, vol. 10, Dec. 2022, doi: 10.3389/fenvs.2022.1021862.

[14] I. Khan, H. Lei, A. A. Shah, I. Khan, and I. Muhammad, "Climate change impact assessment, flood management, and mitigation strategies in Pakistan for sustainable future," *Environ Sci Pollut Res*, vol. 28, no. 23, pp. 29720–29731, Jun. 2021, doi: 10.1007/s11356-021-12801-4.

[15] M. A. Jan *et al.*, "Deconstructing urban flooding from the perspective of vulnerable communities in Northwestern Pakistan," *Front. Hum. Dyn.*, vol. 8, Apr. 2026, doi: 10.3389/fhumd.2026.1751158.

[16] *Global Climate Risk Index 2020 Who Suffers Most from Extreme Weather Events? Wether-Related Loss Events in 2018 and 1999 to 2018*. Bonn: Germanwatch Nord-Süd Initiative e.V, 2019.

[17] Nazam Maqbool, "Impact of Climate Change on Water in Pakistan," https://pide.org.pk/. Accessed: May 08, 2026. [Online]. Available: https://pide.org.pk/research/impact-of-climate-change-on-water-in-pakistan/

[18] W. Ishaque, R. Tanvir, and M. Mukhtar, "Climate Change and Water Crises in Pakistan: Implications on Water Quality and Health Risks," *Journal of Environmental and Public Health*, vol. 2022, no. 1, p. 5484561, 2022, doi: 10.1155/2022/5484561.

[19] J. Green *et al.*, "Review article: A comprehensive review of compound flooding literature with a focus on coastal and estuarine regions," *Natural Hazards and Earth System Sciences*, vol. 25, no. 2, pp. 747–816, Feb. 2025, doi: 10.5194/nhess-25-747-2025.

[20] J. P. M. Syvitski and G. R. Brakenridge, "Causation and avoidance of catastrophic flooding along the Indus River, Pakistan," *The Geological Society of America*, vol. 23, no. 1, 2013, doi: 10.1130/GSATG165A.1.

[21] United Nations Office for Disaster Risk Reduction and International Science Council, "UNDRR–ISC Hazard Information Profiles – 2025 Update: MH0610 Snowmelt Flooding," UNDRR Hazard Information Profiles. Accessed: Jul. 04, 2026. [Online]. Available: https://www.undrr.org/understanding-disaster-risk/terminology/hips/mh0610

[22] A. Nazeer, S. Maskey, T. Skaugen, and M. E. McClain, "Changes in the hydro-climatic regime of the Hunza Basin in the Upper Indus under CMIP6 climate change projections," *Sci Rep*, vol. 12, no. 1, p. 21442, Dec. 2022, doi: 10.1038/s41598-022-25673-6.

[23] M. Vojtek, S. Moradi, D. L. De Luca, A. Petroselli, and J. Vojteková, "Fluvial and pluvial flood hazard mapping: combining basin and municipal scale assessment," *Geomatics, Natural Hazards and Risk*, vol. 15, no. 1, p. 2432377, Dec. 2024, doi: 10.1080/19475705.2024.2432377.

[24] U. Rasool *et al.*, "Quantifying pluvial flood simulation in ungauged urban area; A case study of 2022 unprecedented pluvial flood in Karachi, Pakistan," *Journal of Hydrology*, vol. 655, p. 132905, Jul. 2025, doi: 10.1016/j.jhydrol.2025.132905.

[25] J. H. Weeks *et al.*, "Sea-Level Rise in Pakistan: Recommendations for Strengthening Evidence-Based Coastal Decision-Making," *Hydrology*, vol. 10, no. 11, p. 205, Nov. 2023, doi: 10.3390/hydrology10110205.

[26] A. Zia, I. A. Rana, H. S. H. Arshad, Z. Khalid, and A. Nawaz, "Monsoon flood risks in urban areas of Pakistan: A way forward for risk reduction and adaptation planning," *Journal of Environmental Management*, vol. 336, p. 117652, Jun. 2023, doi: 10.1016/j.jenvman.2023.117652.

[27] A. Nazir *et al.*, "Flood-Induced Agricultural Damage Assessment: A Case Study of Pakistan," *Water*, vol. 17, no. 21, p. 3060, Jan. 2025, doi: 10.3390/w17213060.

[28] N. A. Khan *et al.*, "Flood risk assessment in the Swat river catchment through GIS-based multi-criteria decision analysis," *Front. Environ. Sci.*, vol. 13, Apr. 2025, doi: 10.3389/fenvs.2025.1567796.

[29] S. Mahmood and A. Rahman, "Flash flood susceptibility modeling using geo-morphometric and hydrological approaches in Panjkora Basin, Eastern Hindu Kush, Pakistan," *Environ Earth Sci*, vol. 78, no. 1, p. 43, Jan. 2019, doi: 10.1007/s12665-018-8041-y.

[30] S. Deen, "Pakistan 2010 floods. Policy gaps in disaster preparedness and response," *International Journal of Disaster Risk Reduction*, vol. 12, pp. 341–349, Jun. 2015, doi: 10.1016/j.ijdrr.2015.03.007.

[31] Z. U. Rahman *et al.*, “GIS-based flood susceptibility mapping using bivariate statistical model in Swat River Basin, Eastern Hindukush region, Pakistan,” *Front. Environ. Sci.*, vol. 11, Jul. 2023, doi: 10.3389/fenvs.2023.1178540.

[32] W. Hussain and M. A. Khan, “Climate change-induced Glacial Lake Outburst Floods in Hunza Valley of Pakistan: an assessment of indigenous farming community perceptions and adaptation,” *Environ Dev Sustain*, vol. 26, no. 5, pp. 11515–11539, May 2024, doi: 10.1007/s10668-023-03396-6.

[33] B. Naeem *et al.*, “Flood Hazard Assessment for the Tori Levee Breach of the Indus River Basin, Pakistan,” *Water*, vol. 13, no. 5, p. 604, Jan. 2021, doi: 10.3390/w13050604.

[34] K. Hewitt and J. Liu, “Ice-Dammed Lakes and Outburst Floods, Karakoram Himalaya: Historical Perspectives on Emerging Threats,” *Physical Geography*, vol. 31, no. 6, pp. 528–551, Nov. 2010, doi: 10.2747/0272-3646.31.6.528.

[35] “Flood Forecasting Division — Real-Time Flood Monitoring — FFD Lahore,” Flood Forecasting Division — FFD Lahore. [Online]. Available: https://ffd.pmd.gov.pk

[36] H. N. Hashmi, Q. T. M. Siddiqui, A. R. Ghumman, M. A. Kamal, and H. ur R. Mughal, “A Critical Analysis of 2010 Floods in Pakistan,” *African Journal of Agricultural Research*, Feb. 2012.

[37] A. U. Khan, R. N. A. Khan, and M. Naseer, “2022 Floods in Balochistan and the Socio-Economic Context of the Region,” *Qlantic Journal of Social Sciences*, vol. 5, no. 4, pp. 26–33, Nov. 2024, doi: 10.55737/qjss.768731573.

[38] R. Shahid and T. A. Ali, “The 2025 Cloudburst Crisis in Pakistan: A Narrative Review of Impacts on Human Lives and Livelihood,” *Journal of Health and Climate Change*, vol. 4, no. 2, Mar. 2026, Accessed: Jul. 06, 2026. [Online]. Available: https://jhcc.supp.journalrmc.com/index.php/public/article/view/54

[39] M. Ali and S. Mahmood, “Geo-spatial assessment of pluvial floods in city district Lahore, Pakistan,” *Environ Monit Assess*, vol. 196, no. 2, p. 189, Jan. 2024, doi: 10.1007/s10661-023-12291-6.

[40] A. Ashraf, R. Naz, and R. Roohi, “Glacial lake outburst flood hazards in Hindukush, Karakoram and Himalayan Ranges of Pakistan: implications and risk analysis,” *Geomatics, Natural Hazards and Risk*, vol. 3, no. 2, pp. 113–132, Jun. 2012, doi: 10.1080/19475705.2011.615344.

[41] FFD (2025), “Annual Flood Reports FFD 2025,” Flood Forecasting Division — FFD Lahore. [Online]. Available: https://ffd.pmd.gov.pk/flood-reports

[42] FFC (2024), “Annual Flood Report 2024,” Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2024. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2025/12/ANNUAL-REPORT-2024-FFC.pdf

[43] F. Roth, B. Bauer-Marschallinger, M. E. Tupas, C. Reimer, P. Salamon, and W. Wagner, “Sentinel-1-based analysis of the severe flood over Pakistan 2022,” *Natural Hazards and Earth System Sciences*, vol. 23, no. 10, pp. 3305–3317, Oct. 2023, doi: 10.5194/nhess-23-3305-2023.

[44] L. Akram, “Pakistan’s Flood History: Analysing the Causes and Consequences of a Recurrent Disaster,” in *Flood Risk Reduction: Cutting-Edge Strategies and Innovative Technologies*, S. Mahmood, Ed., Cham: Springer Nature Switzerland, 2026, pp. 135–147. doi: 10.1007/978-3-032-12225-4_7.

[45] “A critical analysis of 2010 floods in Pakistan.,” CABI Databases. Accessed: Jul. 05, 2026. [Online]. Available: https://www.cabidigitallibrary.org/doi/full/10.5555/20123095763

[46] M. Manzoor, S. Bibi, M. Manzoor, and R. Jabeen, “Historical Analysis of Flood Information and Impacts Assessment and Associated Response in Pakistan (1947-2011),” *Research Journal of Environmental and Earth Sciences*, vol. 5, no. 3, pp. 139–146, Mar. 2013.

[47] Atta-ur-Rahman and A. N. Khan, “Analysis of 2010-flood causes, nature and magnitude in the Khyber Pakhtunkhwa, Pakistan,” *Nat Hazards*, vol. 66, no. 2, pp. 887–904, Mar. 2013, doi: 10.1007/s11069-012-0528-3.

[48] S. Mahmood, A.-H. Khan, and S. M. Mayo, “Exploring underlying causes and assessing damages of 2010 flash flood in the upper zone of Panjkora River,” *Nat Hazards*, vol. 83, no. 2, pp. 1213–1227, Sep. 2016, doi: 10.1007/s11069-016-2386-x.

[49] FFC (2020), “Annual Flood Report 2020,” Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2020. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2021/04/2020-Annual-Report-of-Oo-CEA-CFFC.pdf

[50] N. Mujahid, N. Malik, and M. P. Scholar, “The Macroeconomics of Flood: A Case Study of Pakistan,” 2016.

[51] F. M. Qamer *et al.*, “A framework for multi-sensor satellite data to evaluate crop production losses: the case study of 2022 Pakistan floods,” *Sci Rep*, vol. 13, no. 1, p. 4240, Mar. 2023, doi: 10.1038/s41598-023-30347-y.

[52] O. Shabir, “A Summary Case Report on the Health Impacts and Response to the Pakistan Floods of 2010,” *PLoS Curr*, vol. 5, p. ecurrents.dis.cc7bd532ce252c1b740c39a2a827993f, Apr. 2013, doi: 10.1371/currents.dis.cc7bd532ce252c1b740c39a2a827993f.

[53] K. Ullah and J. Zhang, “GIS-based flood hazard mapping using relative frequency ratio method: A case study of Panjkora River Basin, eastern Hindu Kush, Pakistan,” *PLOS ONE*, vol. 15, no. 3, p. e0229153, Mar. 2020, doi: 10.1371/journal.pone.0229153.

[54] M. Yaseen, Y. Latif, M. Waseem, M. K. Leta, S. Abbas, and H. Akram Bhatti, “Contemporary Trends in High and Low River Flows in Upper Indus Basin, Pakistan,” *Water*, vol. 14, no. 3, p. 337, Jan. 2022, doi: 10.3390/w14030337.

[55] M. W. Yaseen, M. Awais, K. Riaz, M. B. Rasheed, M. Waqar, and S. Rasheed, “Artificial Intelligence Based Flood Forecasting for River Hunza at Danyor Station in Pakistan,” *Archives of Hydro-Engineering and Environmental Mechanics*, vol. 69, no. 1, pp. 59–77, Jan. 2022, doi: 10.2478/heem-2022-0005.

[56] M. Ali, “Assessing climate-driven impacts on Karakoram glacier surge: A geospatial analysis highlighting Shishper Glacial Lake outburst flood events (2019–2022) as prime example,” *Heliyon*, vol. 10, no. 16, Aug. 2024, doi: 10.1016/j.heliyon.2024.e35951.

[57] U. Rasool *et al.*, “Rainfall-driven machine learning models for accurate flood inundation mapping in Karachi, Pakistan,” *Urban Climate*, vol. 49, p. 101573, May 2023, doi: 10.1016/j.uclim.2023.101573.

[58] A. Aziz, M. Ali, S. Hassan, F. Nawaz, and F. Sheikh, “Flood Risk Analysis in Sindh, Pakistan: Predicting the Most Affected Tehsil Using Statistical and Machine Learning Models with Comprehensive Data,” *The Asian Bulletin of Big Data Management*, vol. 4, Aug. 2024, doi: 10.62019/abbdm.v4i3.190.

[59] F. A. Khan *et al.*, “Complex Extreme Sea Levels Prediction Analysis: Karachi Coast Case Study,” *Entropy*, vol. 22, no. 5, p. 549, May 2020, doi: 10.3390/e22050549.

[60] S. Taseen, S. Jawed, and A. M. Ameen, “Cholera outbreak amidst urban flooding in Karachi: An emergency condition,” *Annals of Medicine and Surgery*, vol. 81, Sep. 2022, doi: 10.1016/j.amsu.2022.104365.

[61] F. Ejaz, A. Kausar, A. Khan, and H. Arif, “Urban Flooding and Climate Change Vulnerability-A Case Study of North Karachi,” Aug. 2024.

[62] M. A. Jan *et al.*, “Human dimension of urban flood risk and informal resilience in Peshawar, Pakistan,” *Front. Sustain. Cities*, vol. 7, Jan. 2026, doi: 10.3389/frsc.2025.1725174.

[63] M. Tayyab *et al.*, “GIS-Based Urban Flood Resilience Assessment Using Urban Flood Resilience Model: A Case Study of Peshawar City, Khyber Pakhtunkhwa, Pakistan,” *Remote Sensing*, vol. 13, no. 10, p. 1864, Jan. 2021, doi: 10.3390/rs13101864.

[64] A. Baig, S. Atif, and A. Tahir, “Urban development and the loss of natural streams leads to increased flooding,” *Discov Cities*, vol. 1, no. 1, p. 9, Jun. 2024, doi: 10.1007/s44327-024-00010-w.

[65] NDMA (2025), “A Comprehensive Study of Flood Events in Pakistan,” National Institute of Disaster Management (NIDM), NDMA, Islamabad, Pakistan, 2025. [Online]. Available: https://www.ndma.gov.pk/storage/publications/September2025/5a7DeS9RPoaFUxreIcmm.pdf

[66] S. I. Babar and S. Liaqat, “Flash Floods 2022 in Pakistan: Mapping Responses and Challenges,” *University of Wah Journal of Social Sciences*, vol. 8, no. 1, Jun. 2025, doi: 10.56220/uwjss.v8i1.190.

[67] Z. Abbas, “Flood Inundation Modeling and Damage Assessment in Lahore Using Remote Sensing,” *International Journal of Innovations in Science & Technology*, vol. 5, no. 4, pp. 638–647, 2023.

[68] A. Ali, *Indus Basin Floods: Mechanisms, Impacts, and Management*. Asian Development Bank, 2013. Accessed: Jul. 05, 2026. [Online]. Available: https://www.adb.org/publications/indus-basin-floods-mechanisms-impacts-and-management

[69] P. Cui *et al.*, “Flood risk assessment with machine learning: insights from the 2022 Pakistan mega-flood and climate adaptation strategies,” *npj Nat. Hazards*, vol. 2, no. 1, p. 42, May 2025, doi: 10.1038/s44304-025-00096-1.

[70] “Pakistan: Flood Damages and Economic Losses Over USD 30 billion and Reconstruction Needs Over USD 16 billion - New Assessment,” World Bank. Accessed: Jul. 06, 2026. [Online]. Available:

https://www.worldbank.org/en/news/press-release/2022/10/28/pakistan-flood-damages-and-economic-losses-over-usd-30-billion-and-reconstruction-needs-over-usd-16-billion-new-assessme

[71] M. Haq, M. Akhtar, S. Muhammad, S. Paras, and J. Rahmatullah, "Techniques of Remote Sensing and GIS for flood monitoring and damage assessment: A case study of Sindh province, Pakistan," *The Egyptian Journal of Remote Sensing and Space Science*, vol. 15, no. 2, pp. 135–141, Dec. 2012, doi: 10.1016/j.ejrs.2012.07.002.

[72] N. A. Bazai *et al.*, "Dynamics and impacts of monsoon-induced geological hazards: a 2022 flood study along the Swat River in Pakistan," *Natural Hazards and Earth System Sciences*, vol. 25, no. 3, pp. 1071–1093, Mar. 2025, doi: 10.5194/nhess-25-1071-2025.

[73] M. Amin *et al.*, "Mapping and monitoring of glacier lake outburst floods using geospatial modelling approach for Darkut valley, Pakistan," *Meteorological Applications*, vol. 27, no. 1, p. e1877, 2020, doi: 10.1002/met.1877.

[74] S. K. Mondal, V. D. Patel, R. Bharti, and R. P. Singh, "Causes and effects of Shisper glacial lake outburst flood event in Karakoram in 2022," *Geomatics, Natural Hazards and Risk*, vol. 14, no. 1, p. 2264460, Dec. 2023, doi: 10.1080/19475705.2023.2264460.

[75] UNDP / Government of Pakistan, "Scaling-up of Glacial Lake Outburst Floods Risk Reduction in Northern Pakistan (GLOF-II Project)," UNDP. [Online]. Available: https://www.undp.org/pakistan/projects/scaling-glacial-lake-outburst-floods-risk-reduction-northern-pakistan-glof-ii-project

[76] T. Sayama, G. Ozawa, T. Kawakami, S. Nabesaka, and K. Fukami, "Rainfall–runoff–inundation analysis of the 2010 Pakistan flood in the Kabul River basin," *Hydrological Sciences Journal*, vol. 57, no. 2, pp. 298–312, Feb. 2012, doi: 10.1080/02626667.2011.644245.

[77] "Chitral Flash Flood (Monsoon 2015) - July 19, 2015 - Pakistan | ReliefWeb." Accessed: Jul. 05, 2026. [Online]. Available: https://reliefweb.int/report/pakistan/chitral-flash-flood-monsoon-2015-july-19-2015

[78] M. Saleem, M. Arfan, K. Ansari, and D. Hassan, "Analyzing the Impact of Ungauged Hill Torrents on the Riverine Floods of the River Indus: A Case Study of Koh E Suleiman Mountains in the DG Khan and Rajanpur Districts of Pakistan," *Resources*, vol. 12, no. 2, p. 26, Feb. 2023, doi: 10.3390/resources12020026.

[79] -Riaz Khan, A. P. R. Khan, and A. Press, "Flash floods triggered by torrential rains kill at least 176 people in India and Pakistan," PBS News. Accessed: Jul. 05, 2026. [Online]. Available: https://www.pbs.org/newshour/world/flash-floods-triggered-by-torrential-rains-kill-at-least-176-people-in-india-and-pakistan

[80] "Pakistan: Five days of flash floods kill hundreds, cause widespread destruction | Middle East Eye." Accessed: Jul. 05, 2026. [Online]. Available: https://www.middleeasteye.net/news/pakistan-five-days-flash-floods-kill-hundreds-widespread-destruction

[81] A. C. Ali Marium, "Behind Pakistan's repeated floods: Melting glaciers, depleted forests," Al Jazeera. Accessed: Jul. 05, 2026. [Online]. Available: https://www.aljazeera.com/news/2025/8/28/behind-pakistans-repeated-floods-melting-glaciers-depleted-forests

[82] S. Atif, M. Umar, and F. Ullah, "Investigating the flood damages in Lower Indus Basin since 2000: Spatiotemporal analyses of the major flood events," *Nat Hazards*, vol. 108, no. 2, pp. 2357–2383, Sep. 2021, doi: 10.1007/s11069-021-04783-w.

[83] R. Ullah, J. Khan, I. Ullah, F. Khan, and Y. Lee, "Investigating Drought and Flood Evolution Based on Remote Sensing Data Products over the Punjab Region in Pakistan," *Remote Sensing*, vol. 15, no. 6, p. 1680, Jan. 2023, doi: 10.3390/rs15061680.

[84] A. Sajjad, J. Lu, X. Chen, C. Chisenga, N. Saleem, and H. Hassan, "Operational Monitoring and Damage Assessment of Riverine Flood-2014 in the Lower Chenab Plain, Punjab, Pakistan, Using Remote Sensing and GIS Techniques," *Remote Sensing*, vol. 12, no. 4, p. 714, Jan. 2020, doi: 10.3390/rs12040714.

[85] L. Cui *et al.*, "Spatiotemporal Evolution Characteristics of 2022 Pakistan Severe Flood Event Based on Multi-Source Satellite Gravity Observations," *Remote Sensing*, vol. 16, no. 9, p. 1601, Jan. 2024, doi: 10.3390/rs16091601.

[86] S. Akbar, A. Nazir, S. Ali Shah, A. Hadayat, and H. A. Almohammad, "URBAN FLOODING ASSESSMENT DUE TO CLIMATE CHANGE DURING MONSOON SEASON: A CASE STUDY IN ISLAMABAD AND RAWALPINDI," *eco.clim.change*, vol. 3, no. 2, pp. 85–88, 2022, doi: 10.26480/efcc.02.2022.85.88.

[87] A. A. Shah, S. Khwaja, B. A. Shah, Q. Reduan, and Z. Jawi, "Living With Earthquake and Flood Hazards in Jammu and Kashmir, NW Himalaya," *Front. Earth Sci.*, vol. 6, Nov. 2018, doi: 10.3389/feart.2018.00179.

[88] M. Kanwal, "Flash Floods and Cloudbursts in Pakistan (2020-2025)," Sep. 27, 2025, *Social Science Research Network, Rochester, NY*: 5537760. doi: 10.2139/ssrn.5537760.

[89] FFC (2010), "ANNUAL FLOOD REPORT-2010," Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2010. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2020/06/Annual-Flood-Report-2010.pdf

[90] FFC (2011), "ANNUAL FLOOD REPORT-2011," Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2011. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2020/06/Annual-Flood-Report-2011.pdf

[91] FFC (2014), "ANNUAL FLOOD REPORT-2014," Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2014. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2020/06/Annual-Flood-Report-2014.pdf

[92] FFC (2022), "Annual Flood Report 2022," Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2022. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2023/11/Final-Annual-Report-2022-Oo-CEA-CFFC.pdf

[93] Government of Pakistan / UNDP (2022)., "Pakistan Floods 2022: Post-Disaster Needs Assessment (PDNA)," UNDP. Accessed: Jun. 08, 2026. [Online]. Available: https://www.undp.org/pakistan/publications/pakistan-floods-2022-post-disaster-needs-assessment-pdna

[94] Provincial Disaster Management Authority - Sindh, "Flood 2022 in Sindh," Provincial Disaster Management Authority - Sindh, Rehabilitation Department, Government of Sindh, Sindh, Pakistan, Government report, 2023. [Online]. Available: https://pdma.gos.pk/Documents/Reports/Flood%202022%20In%20Sindh.pdf

[95] M. J. Butt, M. Umar, and R. Qamar, "Landslide dam and subsequent dam-break flood estimation using HEC-RAS model in Northern Pakistan," *Nat Hazards*, vol. 65, no. 1, pp. 241–254, Jan. 2013, doi: 10.1007/s11069-012-0361-8.

[96] D. Shangguan *et al.*, "Determining the Events in a Glacial Disaster Chain at Badswat Glacier in the Karakoram Range Using Remote Sensing," *Remote Sensing*, vol. 13, no. 6, p. 1165, Jan. 2021, doi: 10.3390/rs13061165.

[97] S. Muhammad *et al.*, "A holistic view of Shisper Glacier surge and outburst floods: from physical processes to downstream impacts," *Geomatics, Natural Hazards and Risk*, vol. 12, no. 1, pp. 2755–2775, Jan. 2021, doi: 10.1080/19475705.2021.1975833.

[98] S. Sarfaraz and N. Faisal, "Climate Change and its Impacts across Pakistan: Climate Change and its Impacts across Pakistan," *International Journal of Economic and Environmental Geology*, vol. 14, no. 04, pp. 28–39, Nov. 2023, doi: 10.46660/ijeeg.v14i04.196.

[99] M. N. Ahmad, Z. Shao, and A. Javed, "Mapping impervious surface area increase and urban pluvial flooding using Sentinel Application Platform (SNAP) and remote sensing data," *Environ Sci Pollut Res*, vol. 30, no. 60, pp. 125741–125758, Dec. 2023, doi: 10.1007/s11356-023-30990-y.

[100] A. Ashraf, M. Jabeen, S. A. Ditta, and Z. Ahmad, "Examining groundwater sustainability through influential floods in the Indus Plain, Pakistan," *Sustain. Water Resour. Manag.*, vol. 9, no. 2, p. 56, Mar. 2023, doi: 10.1007/s40899-023-00836-z.

[101] FFC (2018), "ANNUAL FLOOD REPORT-2018," Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2018. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2020/06/Annual-Flood-Report2018.pdf

[102] FFC (2015), "Annual Flood Report 2015," Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2015. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2020/06/Annual-Flood-Report-2015.pdf

[103] FFC (2012), "ANNUAL FLOOD REPORT-2012," Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2012. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2020/06/Annual-Flood-Report-2012.pdf

[104] FFC (2013), "ANNUAL FLOOD REPORT-2013," Federal Flood Commission, Ministry of Water Resources, Government of Pakistan,

Islamabad, Pakistan, 2013. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2020/06/Annual-Flood-Report-2013.pdf

[105] FFC (2016), “ANNUAL FLOOD REPORT-2016,” Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2016. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2020/06/Annual-Flood-Report-2016.pdf

[106] FFC (2017), “ANNUAL FLOOD REPORT-2017,” Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2017. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2020/06/Annual-Flood-Report-2017.pdf

[107] FFC (2019), “ANNUAL FLOOD REPORT-2019,” Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2019. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2020/06/Annual-Flood-Report-2019.pdf

[108] FFC (2021), “ANNUAL FLOOD REPORT-2021,” Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2021. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2020/06/Annual-Flood-Report-2021.pdf

[109] FFC (2023), “ANNUAL FLOOD REPORT-2023,” Federal Flood Commission, Ministry of Water Resources, Government of Pakistan, Islamabad, Pakistan, 2023. [Online]. Available: https://ffc.gov.pk/wp-content/uploads/2020/06/Annual-Flood-Report-2023.pdf