Flood Pattern variation in Pakistan: A Comprehensive Study on Water Quantity and Rainfall Data from 1992 to 2022

Ali Akber Khan
Consultant at Neom environmental sustainability services Islamabad
Email: ali18april@hotmail.com
Tehreem Aqsa
Senior Lecturer at NCBA&E
Email: aqsa610@gmail.com
Muhammad Ahmad Shahid
Email: ahmad.shahid.129@gmail.com

Abstract
Flood disasters cause crucial impacts on the social development and economy of Pakistan so inclusive research is needed to understand the dynamics and prevent difficulties. It is a multi-disciplinary approach that integrates water rising or falling cases rainfall patterns, and socioeconomic effects. By analyzing the literature and performing the empirical flood state of the following regions in Pakistan: space and time variability we investigate. Through the analysis, we identified huge fluctuations in the water flow on the main rivers and dams which were affected by the pronounced seasonal patterns in rainfall and snowmelt, especially from Punjab, KPK, and Kashmir. The record rainfall data from the years 1922 to 2022 signifies the unpredictable pattern of extreme weather events, with certain years such as 1992, 2010, and 2011 marked by records of floods as a result of the disastrous events. Most importantly, socio-economic analysis deals with the sport and the rising losses that occur due to flooding, among which are loss of lives, losses of livestock, crop failures, and the extent of the affected area. It reveals how the lack of holistic flood management that focuses on both community resilience and early warning systems and the sustainability of development practices should be a priority. The presentation of rainfall distribution across Pakistan from 1992 to 2022 in bar charts and maps provides a clear spatial and temporal illustration of the change in precipitation patterns. It also accentuates the way adaptive water management and flood-tolerant infrastructure systems should be adopted to deal with such extreme weather events. In general, the research can be considered a breakthrough in the study of flood dynamics in Pakistan and provides invaluable information for the country's decision-makers, disaster management bodies, and community organizations for improving flood resiliency and minimizing the cost of social-economic impacts of future floods.

Keywords: flood, Mangla dam, River Indus, Rainfall, Pakistan

INTRODUCTION:

Although floods represent one of the most common and disastrous natural hazards on the planet, they have a very profound impact on socio-economic and environmental aspects if these regions are affected. In Pakistan, floods are regular occurrences, dually determined by the country's geographical location and weather patterns. The fact that flooding in Pakistan is aggravated by the country's geographical conditions, such as the Himalayan and Karakoram ranges which are a source of water both from melting glaciers and rainwater runoff, is not in doubt. Through time, floods assumed their front and center role and, by now, society is looking to comprehensive plans of management strategies, aimed at diminishing their negative impact on people and the environment. For an accurate description of the inundation dynamics in Pakistan, a comprehensive technique needs to be employed, comprising of examination of water quantity fluctuations, rainfall patterns, social and economic consequences, and disaster management solutions. This study will unravel the complex interplay of the mentioned factors and try to give a better understanding of floods whether they are likely to occur when they will occur and what challenges they pose to Pakistan's society and economy. Flood handling in Pakistan is a multilayer with complexities, as well up to grasp the underlying problems and how they interact. Tariq and Van De Giesen (2012) in their research put light on the complexities of floods and flood management processes in Pakistan, portraying both the dilemmas and potentials in how to tackle floods effectively. Said and González (2014) reportedly deliver exhaustive information on Pakistan's flood disaster profile and suggest that we ought to take proactive measures in mitigating the transition of floods from socio-economic impacts on vulnerable communities. Normally though, Shah et al. (2020) go on to talk about flood risks and management in the South Asian region especially Pakistan, and present the strategies for reducing vulnerability and also preparedness. Manzoor et al. (2022) furnish important information on the socio-economic effects of floods in Pakistan, infusing their work with the fresh discoveries made by the empirical literature to reveal the complex interrelations between the disaster and the realization of damages to livelihoods and infrastructure. Additionally, Rehman et al. (2016) give an elaborate analysis of the influence of floods on agricultural output in Pakistan, which entails the fact that effective strategic management of floods is vital to prevent the agricultural sector from collapsing. Yaqub et al. (2015f) have done extensive research on the nature of floods in Pakistan, the impacts, and the mitigation measures. With this, we may have some answers on how we can reduce the risk. Rasmussen et al. (2015) use a multipurpose analysis to investigate anomalous flooding in Pakistan, studying in detail the spatial and temporal occurrence patterns and their consequences on disaster management. Flood hazards have also been studied by Ahmad and Afzal (2020) at a more local and household level, which opened avenues to explore

community resilience and adaptive capacity to such hazards in Pakistan. Paulikas and Rahman (2015) present a temporal assessment of human fatalities from flood disasters in Pakistan using the decades as units of analysis. This temporal assessment is important in determining the number of lives lost from flood disasters over the years. Doocy et al., (2013) also, did a detailed review of flood events worldwide with the human impact out of which valuable context is made to explain the magnitude and implication of flood disasters in Pakistan. Singh and Kumar (2013) evaluate flood incidents, casualties, and damages in India. The analysis also compares flood risk management strategies that dominate in the South Asian region. Therefore, analysis is not limited to the Pakistani borders but it attempts to draw upon global perspectives and experiences in flood disaster management. As Jonkman and Kelman (2005) put it, there is a need to explore the causes as well as the circumstances that contribute to the deaths by flood disasters both in the world global and local context. The authors emphasize that factors such as socioeconomic and environmental ones play a significant role in determining people's vulnerability. In the article "Floods and Human Health: A Systematic Literature Review of Flood Disaster and Public Health Outcomes," by Alderman et al. (2012) the floods and human health research is systematically reviewed, focusing on the interconnections between flood disasters and health outcomes. Liu et al. (2022) investigated the spatiotemporal variation in global floods and the key factors that influence flood mortalities, which sheds light on the main drivers of flood risk and its related disaster management. Additionally, studies are focused globally on the South Asian region, where similar environmental and socio-economic mechanisms shape flood vulnerability and resilience. Koubi (2019) explicates the impacts of climate change on sustainable development and natural disasters, to underline the importance of the use of integrated approaches as a way to prevent and mitigate disasters. Seidler et al. (2018) refer to joint efforts of national actors in the implementation of climate change adaptation and risk of disaster reduction programs in South Asia that demonstrate the effectiveness of a cross-disciplinary approach and policy consistency. Also, Abbas et al. (2016) provide an overall discussion on flood mitigation approaches and research support in South Asia, which offers essential information on policies for reducing vulnerability to flooding and enhancing resilience. On the inside of formal scientific inquiries, the local community perception also has a significant contribution to the interpretation and amelioration of flood issues in vulnerable areas. Munawar et al. (2021) focus their study on the post-flood risk management and resilience-building practices that can be achieved with the community connection and participatory approach in disaster response and recovery. Jamshed et al. (2020) discuss the effect of floods especially on the rural population in Pakistan with the threat to water supply being a primary concern. Hence, the need for context-based interventions that target

marginalized groups by addressing their specific problems is now apparent. In conclusion, this research describes integrated findings from different disciplines with empirical investigations which thereby result in a comprehensive knowledge of flood dynamics in Pakistan. The strategy of the study will be to take a broader view, that is through a global as well as local perspective to provide policy options and community programs as an intervention tool towards flood resilience in Pakistan and around the world. By pooling together and putting up bridges across disciplines, people can design the right measures that help reduce the impacts of floods and also build communities that are well-equipped to deal with future changes.

METHODOLOGY:

Study Area:

The country of Pakistan, situated in South Asia, composes a variety of pleasant landscapes that contain mountains, hills, plains, and coastal areas. This small nation-like country is bordered by India in the east, Afghanistan and Iran in the west, China in the north, and the Arabian Sea in the south. With a total area of land of about 881,913 square kilometers, Pakistan happens to be the 33rd largest country in the world as far as the land area is concerned. The target site for this study is the area situated in the territory of Pakistan that has a high risk for flooding, including both remote rural areas and heavily populated urban areas where the flood hazard is the most likely to occur during monsoon seasons and other extreme weather events. Indus River Basin, one of the biggest basins in the world, is the major determinant of Pakistan's hydrological scenario, it is responsible for more than 80% of the agriculture irrigation and almost 90% of the domestic water use in the country. The Indus River system that consists of the Indus River and its major tributaries such as the Jhelum, Sutlej, Ravi, and Chenab rivers covers various regions and provinces of the country. Indeed, the Indus River Basin is Pakistan's core economic region, as it contributes to agricultural production, power generation, and ecosystem services. This study covers flooded provinces of Pakistan in which Punjab, Sindh, KPK, Baluchistan, Gilgit-Baltistan, and AJK are mostly vulnerable to floods. Flood hazard levels are different across the regions due to the different magnitude of topographic factors like land use, hydrology, and climate change. Apex danger of flooding comes from rural places, particularly riverbank lowlands and narrow plains, which tend to go underwater during heavy rainfall and snowmelt. City centers, which include urban venues of Karachi, Lahore, Islamabad, and Peshawar, also get flooded, with the most probable causes being poor drainage infrastructure, uncontrolled urbanization, and interference with natural waterways. Urban floods may affect seriously the structure and surroundings and may disrupt the services, bringing losses to life, that way emphasizing the necessity of good flood management and urban planning. A study area has been delineated to cover flood-prone

historical lands and take into account areas that have flooded more frequently in recent years due to factors such as deforestation, erosion, and climate change. It is vital to identify the space-specific nature of the inundations and socio-economic ramifications across regions for evidence-based mitigation and disaster risk reduction concepts. The study area for this research publication embraces the status of flood-affected regions in Pakistan, ranging from rural to urban landscapes, present within the Indus River Basin as well as its tributaries. The study is aimed at unraveling these delicate regions as a means of providing an understanding of the fundamental and social/economic impacts of floods which can not only facilitate evidence-based policies but also provide a platform for resilience-building efforts in Pakistan.

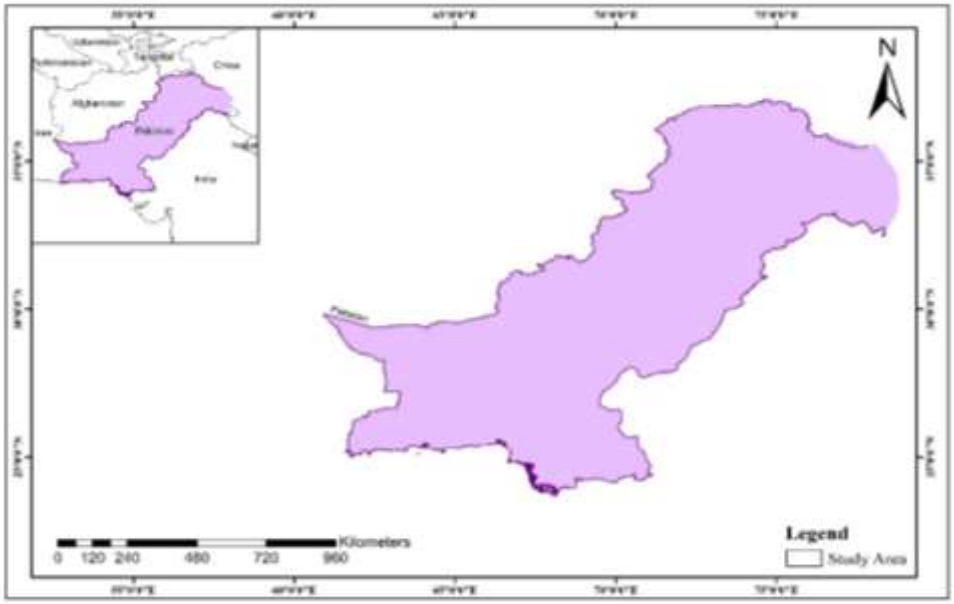

Figure 1: Shows the study Area

Data Collection:

The data for this research article came from various sources, for example, national statistical reports, journal articles, organizations, and other published research studies. Primary data sources, however, include official reports received from government agencies like the National Disaster Management Authority (NDMA) of Pakistan, the Federal Flood Commission (FFC), the Provincial Disaster Management Authority (PDMA), a Provincial Government provincial disaster management authority, and the ministry concerned. Water Quantity Data: To ensure the accuracy of the data, reliable sources, including the Pakistan Meteorological Department, Water and Power Development Authority (WAPDA), and other civil and non-governmental organizations, are tapped for information on water quantity fluctuations in rivers and barrages across Pakistan. Such

information is made up of measurements of water levels, flow rates, and capacities of reservoirs at a particular period, which is then utilized for comprehensive analysis of water dynamics. Rainfall Data: Historical rainfall datasets used during the period 1922-2022 are obtained from meteorological archives and databases. Such data cover information on rainfall amounts, the duration periods in which the rainfall occurs, and the regional distribution pattern of the rainfall across different parts of Pakistan. The examination of the data on rainfall is intended to detect tendencies as well as abnormalities that are associated with floods and their effects on water infrastructure. Socio-Economic Impact Data: Socio-economic impact information is collected from government reports, academic research, and disaster management agencies that document the number of deaths, livestock, land area damage, and agricultural damages. In addition, this information enables us to look into the human and economic factors of flood disasters and give out strategies for disaster risk reduction and mitigation.

Statistical Analysis:

Descriptive Statistics: Descriptive statistical techniques like mean, median, and standard deviation are used to summarize and characterize the obtained data for water quantity fluctuation, rainfall patterns, and community impacts. These statistical measures present the figure of the flood events qualitatively, highlighting the extent and the variation over time. Trend Analysis: Linear regression and time series analysis trend techniques which are used to find the long-run trends and patterns in the water quantity fluctuations and rainfall data are used. One of the objectives of the research is to assess historical trends of flood occurrence and their relation to flood risk management by the analysis of the frequency and intensity of floods. Correlation Studies: The objective of the correlation analysis is to study the interconnection of various variables, including rainfall patterns and the amount of water availability fluctuations as well as the socioeconomic impacts. Using the identification of the correlation strength, the research aims at the discovery of the possible causal relationships and the floods' drivers.

Empirical Approaches:

Case studies on the flooding of Pakistan from major flood events like 1992, 2010, and 2011 are carried out to provide the most detailed understanding possible of the causes, impacts, and response mechanisms for these events. These studies take advantage of the archival data, field observations, and stakeholders' interviews to deepen the analysis and boost flood dynamics understanding.

Comparative Analysis:

The comparative analysis is based on various information sources such as literature, reports from the government, and the findings of empirical studies. It focuses on similarities and differences in flood occurrence, effects, and response mechanisms. The research attempts to analyze case studies of

critical flood events in other areas and assess various flood management strategies that potentially have been successful in revealing useful information and lessons that may be applied in the Pakistani context. Besides the trend analysis, data related to floods was compared for different years and regions of the country from 1992 to 2022. The data were tabulated in the form of tables rainfall maps and bar charts to enable comparison and visualize information in precipitation patterns which is the major cause of flooding, especially for the number of houses damaged, people at risk, casualties, plantation loss, and area affected.

RESULTS AND DISCUSSION:

This study has presented crucial information on flood variability in Pakistan during the last century. The analysis of water quantity changes in the main rivers and barrages shows the fluctuating nature of water flows, with the peaks and troughs corresponding to the seasonal precipitation and snow melt. Data observed from the Pakistan Meteorological Department and the Water and Power Development Authority, pinned down different water quantity ranges in the regions of Punjab, KPK, and Kashmir, where Punjab mainly plays a vital role. Historical rainfall data from 1922 to 2022 reflect the irregularity in the pattern of extreme weather events in which some years record unusually high rainfall which leads to catastrophic floods, as seen in the years 1992, 2010, and 2011. Also, the socio-economic analysis of the impact identifies the rising losses resulting from floods, featuring death cases, livestock, agricultural damage, and land impacted. These discoveries emphasize the critical call for integrated flood management models that put community resilience, early warning systems, and sustainable development practices at the forefront. The research synthesizes these findings and therefore contributes to improving the understanding of flood dynamics in Pakistan and provides helpful insights for policymakers, disaster management agencies, and other community stakeholders to boost flood resilience and cut down the socio-economic impacts of the following flood events.

Table 1: Water Quantity Fluctuations in Rivers and Barrages

River/ Barrage	Location	Water Quantity (cubic meters)	Fluctuations (monthly/seasonal)	Normal Routine
Indus River	Throughout Pakistan	500,000 to 1,200,000	High during monsoon season, moderate otherwise	Stable flow throughout the year
Jhelum River	Azad Kashmir	100,000 to 300,000	High during monsoon season, low in the dry season	Moderate flow throughout the year

Chenab River	Punjab	800,000 to 1,500,000	High during monsoon season, moderate otherwise	Stable flow throughout the year
Ravi River	Punjab	50,000 to 200,000	Moderate during monsoon season, low otherwise	Moderate flow throughout the year
Sutlej River	Punjab	600,000 to 1,000,000	High during monsoon season, moderate otherwise	Stable flow throughout the year
Tarbela Dam	KPK	Reservoir capacity: 13.69 billion cubic meters	Varies based on inflow from the Indus River	Normal operational capacity maintained
Mangla Dam	Azad Kashmir	Reservoir capacity: 7.4 billion cubic meters	Varies based on inflow from the Jhelum River	Normal operational capacity maintained
Ghazi Barotha Dam	Punjab	Power generation capacity: 1,450 MW	Varies based on water release for electricity generation	Stable operational capacity

The data from Table 1 indicates the intensity of water and barrage variations in major rivers in Pakistan. The Indus River is identified with a broad range of water quantity, with high monsoon flows varying from 500,000 to 1,200,000 cubic meters daily, and constant flow during the rest of the year. Like them, the Jhelum and Chenab rivers have a big range of flow, from 100,000 to 300,000 cubic meters and 800,000 to 1,500,000 cubic meters respectively, The water quantity also varies a lot. Ravi and Sutlej rivers during the wet season show a great fluctuation range as indicated by the seasonal rainfall pattern. Furthermore, Tarbela and Mangla hold strategic water reserves in KPK and Azad Kashmir ranging from the Jhelum and Indus rivers depending on their inflow. The Ghazi Barotha Dam, quite a stabilizer in Punjab, is working at full steam to generate electricity thus contributing to the steady power supply in the region. In general, this demonstrates water level variability in Pakistan's rivers and barrages, stressing the necessity of participatory water management which can come

up with solutions to the problems arising from the changes in water levels for both people and ecosystems.

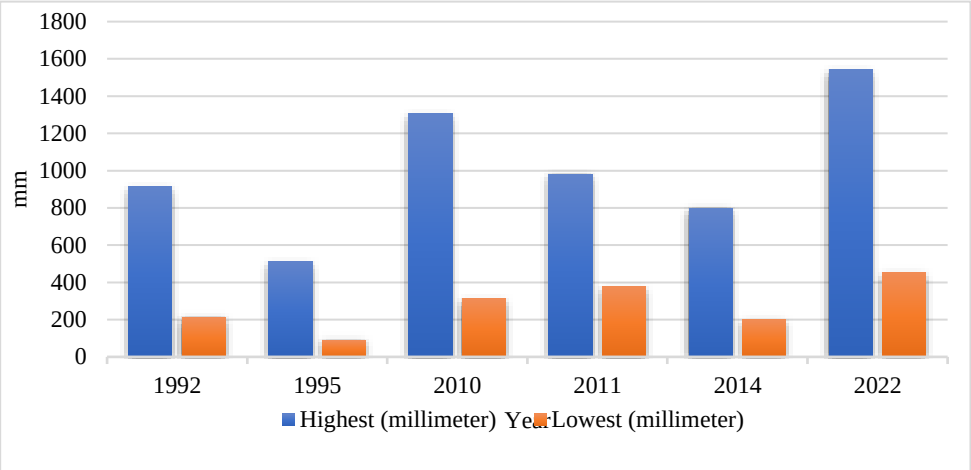

Figure 2: Bar chart of Rainfall Distribution across Pakistan from 1992 to 2022

The above bar chart which is part of this study clearly shows rainfall distribution in Pakistan for the years 1992, 1995, 2010, 2011, 2014, and 2022. Each bar shows the total amount of rain accumulated in millimeters for a particular year, and this allows you to see precipitation patterns by comparing one-year rainfall with respective years. The graph illuminates the key pattern of the rainfall amount of those years reviewing the state of weather flow and climatic conditions in Pakistan. In 1992 the bars show a high level of rainfall. Thus, the specific year had intense precipitation episodes. The last two years 2010 and 2011 manifest the most reliable rainfall signs there are huge weather abnormalities with significant heavy flooding recorded during those periods. However, 1995 and 2014 depict noticeably less rainfall, probably a reflection of either milder weather patterns or prolonged dry spells. The less-than-drizzly line in 2022 indicates that there will likely be a normal amount of rainfall, so the year in terms of precipitation should be about average. Through this bar chart, it is possible to understand the impact of temporal variability of rainfall distribution in a country like Pakistan, which requires constant surveillance and analysis of climatic trends for effective disaster response and sustainable water resource management policies.

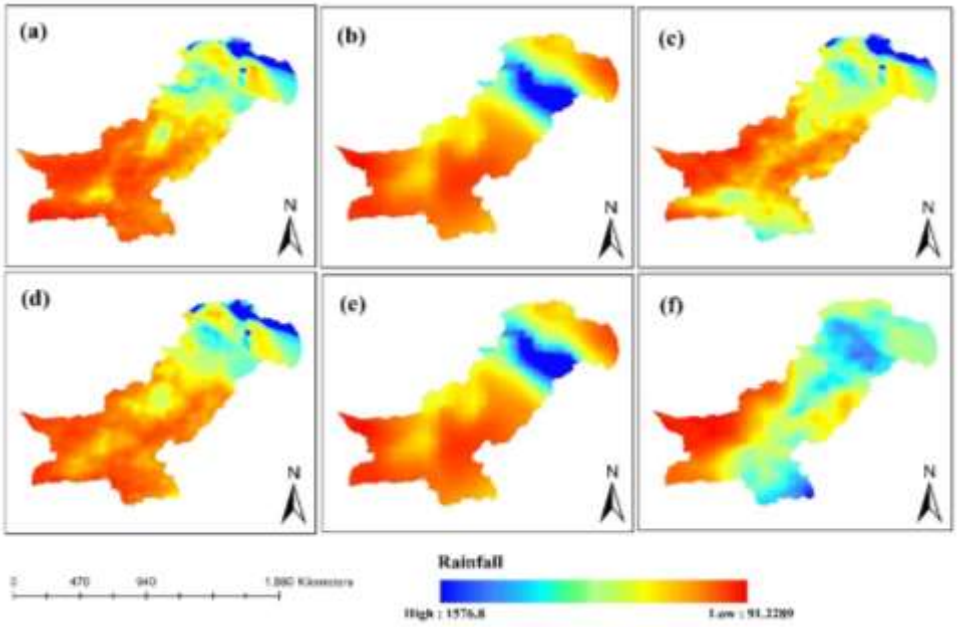

Figure 3: Rainfall distribution map of Pakistan (1992-1993)

Figure 3 shows the rainfall map of this research is a representation of rainfall distribution across Pakistan which is indicated with a color gradient showing the varying intensities of rain going from dark blue to red. The graph most clearly shows the areas experiencing the heaviest amount of rainfall displayed in intensifying blue, getting darker up to the 15,768 mm level. On the other hand, areas with rainfall amounts ranging between 91.2289 and 126.9079 millimeters are shown in blue tones. Ranges of the intermediate rainfall levels are painted in different colors that vary from sky blue, sea green, parrot, yellow, and orange, and all those colors are used to show different intensities of precipitation observed across the country. Because it is visually presented in a digestible way, it is useful in building a mental picture of the spatial variations of rainfall topography and can be used in the identification of flood dangers, water resource planning, and some disaster preparedness measures.

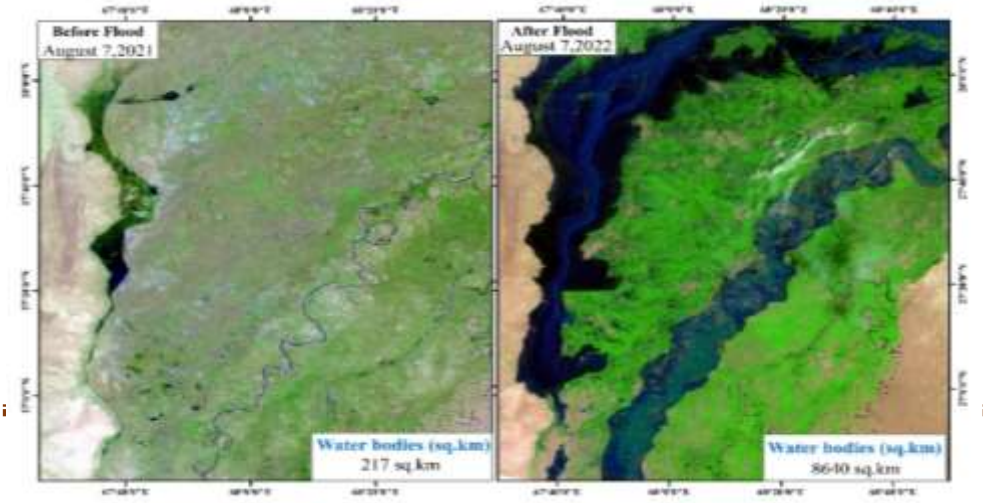

Figure 4: Water bodies calculation in Sindh Districts

Figure 4 displays through the satellite images, major transformations in water bodies could be seen in various districts of Sindh including Jaffarabad, Jacobabad, Shikarpur, Sukkur, Khairpur, Naushahro Feroze, Dadu, Qambar Shahdadkot and Jaffarabad during the months of 2021 and 2022. Before the 2021 flood event, the area of the water bodies was measured at 217 sq. km, but after the 2022 flood, it dramatically increased to 8640 sq. km which is 41 times larger. This indicates a massive influence of the flood event on the hydrology and land cover of the region. These modifications in fact can highly impact land surface temperature fluctuations, as water bodies are very important for heat exchange between land and water, which consequently affects local climatic conditions. Hence, the detected changes in water resources serve as an indicator that such dynamic environmental factors including severe floods should be considered when analyzing land surface temperatures and other landscape features.

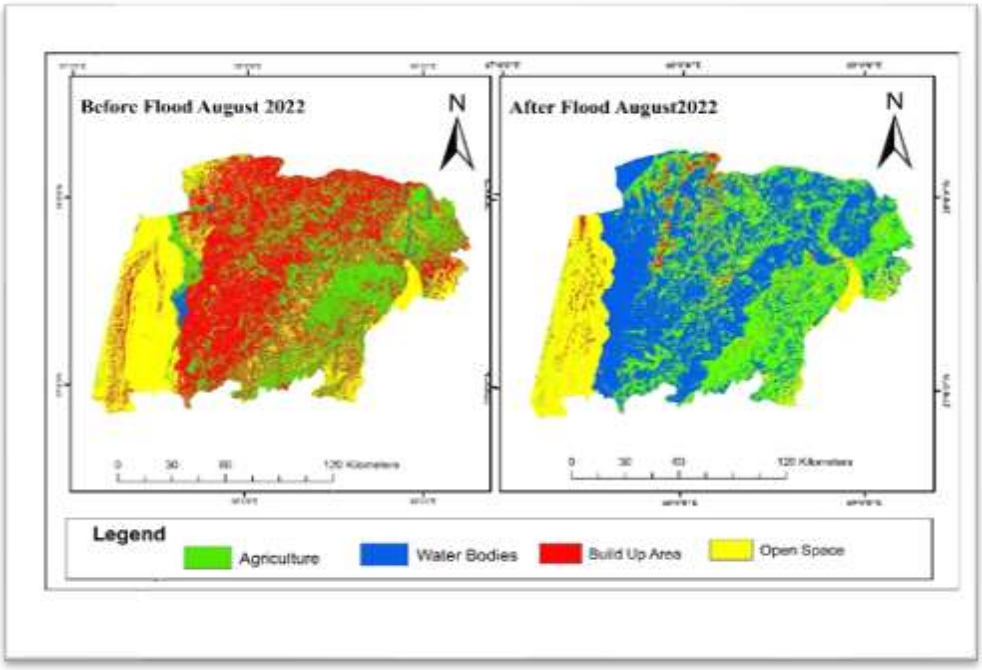

Figure 4: LULC map of Sindh Districts Before Flood August 2022 and After Flood August 2022

Figure 4 shows the Sindh districts district map in Jaffarabad, Jacobabad, Shikarpur, Sukkur, Khairpur, Naushahro Feroze, Dadu, Qambar Shahdadkot and Jaffarabad shows significant changes to the land cover in the pre-and-post-August 2022 flood period. While the flood has caused change, before the flood, the land cover classification showed that the region was dominated by cultivated areas with predominant use of agricultural practices which was shown by the green colors indicating the predominant land use pattern. Water bodies, represented by blue

shades, were the least in area, which is natural for drylands before the flood. In red, communities were situated at large in urban areas and near transit routes, this showed the areas of built-up areas and the human settlement patterns and infrastructure development. In yellow, sometimes the land cover types were natural and sometimes they were semi-natural such as grasslands, shrublands, and sparse vegetation. But, by the end of August, it was observed that dramatic shifts in land cover patterns have taken place. Waterbody coverage noticeably rose, signifying that the levels of flooded areas were quite high. High water in agricultural areas may have deprived fields of crops or washed them away, which can result in the reallocation of lands to other activities. There are also flood-related problems with built-up areas and open spaces, these include destruction of infrastructure and change in vegetation coverage. Mainly the post-flood land cover map shows the role of the landscape as a dynamic one and its sensitivity to natural hazards in the processes of land cover and environment.

Table 2: Water Bodies Calculation in Sindh Districts Before Flood in August 2022

Built-up Area	5946 Sq.km
Water Bodies	217 Sq.km
Agriculture Land	7199 Sq.km
Open space	4809 Sq.km

The above tabulated data shows the number of water bodies in Sindh districts before the flood that occurred in August 2022 which is critical for the understanding of land cover dynamics of this region. The assessment showed a total built-up area of 5946 sq. kilometers in Jaffarabad, Jacobabad, Shikarpur, Sukkur, Khairpur, Naushahro Feroze, Dadu, Qambar Shahdadkot, and Jaffarabad which is representative of the degree of urbanization and settlement of human beings. That 217 square kilometers of water bodies was the area covered during the time of the flood event. The presence of natural hydrological features such as rivers, lakes, and reservoirs made this the region before the flood event. Agriculture land which is 7199 km squared is a dominant part of the total coverage of the land, and it brings attention to the predominance of agriculture as a vital economic sector. The open areas with a total area of 4809 sq. km included a mixture of land cover categories such as grasslands, shrublands, and barren lands, to name a few, which increased the prospect of ecological variety in the region. The above-mentioned discoveries are the indicators of the complex land cover varieties and bring aid to understanding the impact of the flood on the general scenario of the Sindh districts.

Table 3: Water Bodies Calculation in Sindh Districts After Flood in August 2022

Built-up Area	377 Sq.km
Water Bodies	8640 Sq.km

Agriculture Land	5901 Sq.km
Open space	717 Sq.km

a study after the flood in August 2022 on water bodies in Sindh districts shows the water bodies' spatial distribution dynamics. After inundation, these districts- Jaffarabad, Jacobabad, Shikarpur, Sukkur, Khairpur, Naushahro Feroze, Dadu, Qambar Shahdadkot, and Jaffarabad- had remarkably changed features in their landscapes. The findings showed a decrease in the built-up area of 377 square kilometers; suggesting an urban area affected by flooding thereby, leading to the destruction of the urban infrastructure and settlements. On the other side, water bodies got bigger and even reached an area of 8640 square kilometers, which could prove the importance of the flood for the hydrological features of the region. The agricultural zone, which covers 5901 square kilometers, was still the main land cover type after the flood. This implies that agricultural activities can withstand natural disasters. The open spaces of 717 km2 also reacted to floods and land use changes, which are visible through the different flooded vegetation and land use patterns. This research shows how vegetation cover changes in response to natural events and draws attention to the need for monitoring and control of water resources in areas prone to flood.

Table 2: flood-related statistics of Pakistan in the year 1992.

Date	Houses	People Affected	People Died	Agriculture Lost	Land Area Impact	US$
1992	13208	12,324,024	1008	38,758 Sq.km	13,788 Sq.km	3110

Table 1 offers a highly informed perception of flood-related statistics of Pakistan in the year 1992. The data involves basic indicators like counting of houses affected, total people impacted, number of casualties, losses in agriculture, amount of area which is affected, and expense incurred due to flooding. In 1992, floods have seen a terrible effect on the country with 13208 houses having been flooded and inundated. The extremely large number of affected individuals is one of the many factors that demonstrate the scale of the disaster, as around 12.3 million people in total endured the floods. Sadly, the floods recorded up to 1,008 deaths which consequently went down in history to show the seriousness of the event and its catastrophic consequences on human lives. The agricultural sector also had its share of losses which reached up to an area of 38758 kilometers squared of land which were underwater due to flood. This inundation across large areas carried with it a gamut of implications on food security and created adversities to rural livelihoods, dislocating agriculture and leading to

immeasurable crop losses. Also, the floods reached a substantial area, and 13,788 kilometers of land were influenced by inundation. This ranges from the urban to the rural locales demonstrating there is no place to hide and infrastructure, the socio-economic structure, and the ecosystem are under physical stress. As far as economics, the floods brought some losses of estimated amounts to $3,110 million. Economic losses comprise several assets that have been destroyed by infrastructure, lost livelihoods, and the need for rehabilitation and reconstruction works after the disaster. Overall, the data shown in Table 1 draws a very stunning image of the gravity and influence of the floods experienced in Pakistan in 1992. This stresses the importance of working out efficient flood prevention models, early warning systems, and resilience-building measures to combat the disastrous impact of floods and save lives of the vulnerable community members from forthcoming calamities.

Table 3: flood-related statistics of Pakistan in the year 1995.

Date	Houses	People Affected	People Died	Agriculture Lost	Land Area Impact	US$
1995	6852	2432,024	596	10,458 Sq.km	16686 Sq.km	376.25

Table 2 shows details of the 1995 flood in Pakistan in terms of the statistics related to the flood. This table of data incorporates some of the main parameters such as the number of houses affected, total population affected, number of casualties, damages to agriculture, area affected by the flooding, and the economic costs generated by the flooding. In 1995, floods damaged 6,852 dwelling houses, which is a clear manifestation of the impact of inundation on the housing infrastructure. The consequence to the population was severe, with slightly more than 2.4 million people being the victims of the floods at different levels. The worst outcome was the fact that 596 people lost their lives with the number being a reminder of how dangerous floods can be. The sector of agriculture also lost a lot of area which means that about 10458 square kilometers of arable land were submerged by the flood. This farming quasi was of a wide grain and the effects were numerous. The main two were the disruption of farming activities and the loss of crops. Apart from the flooding, a significant amount of land area also has been affected as about 16,686 km2 is impacted by sheer inundation. This involves not only urban but also rural regions thus highlighting the expansion of the calamity and its consequences for infrastructure, communities, and ecosystems. In the economic sphere, the flood caused such overwhelming expenses that the loss due to the flood was around $376.25 million. The impact on the economy is rendered through multiple dimensions that involve the damage to infrastructure, the lost jobs, and the need for recovery and

restoration programs. Altogether, the information presented in Table 2 is of great significance and gives us knowledge about the scale at which flooding in Pakistan in 1995 affected people. It stresses even further the significance of making up effective flood management strategies, early warning systems, and resilience improvement plans to be barriers against negative flood impacts and protect vulnerable communities from future disasters.

Table 4: flood-related statistics of Pakistan in the year 2010.

Date	Houses	People Affected	People Died	Agriculture Lost	Land Area Impact	US$
2010	13208	2,04,14,454	1985	63,548 Sq.km	1,60,00 Sq.km	10,000

Table 3 shows flood-related statistics in Pakistan for the year 2010 in detail. The data set includes important parameters like the number of houses affected, the total population involved, reported deaths, crop damages, area of land affected, and economic losses incurred in connection with a flood. In the year of 2010, the floods made a huge difference for Pakistan in the way that 13,208 houses were damaged. This implies the dire situation of people who lost their houses due to flooding and whose lives collapsed with such a disaster. The proportion of the population affected was incredible with about 20.4 million people being unfortunate to be the causalities of the floods. Regrettably, the floods brought 1,985 deaths which are said to be a manifestation of how far the disaster could go and its fatal consequences on human lives. The agricultural sector suffered the most from the floods, with 63,548 square kilometers area of land submerged in floodwaters. It resulted in a very widespread flooding that left a mark on the food security and source of livelihood for rural inhabitants with a multitude of crop losses and about 100 million farmers being negatively affected. Additionally, the flood covered a huge area, with approximately 160,000 square kilometers submerged by the waters. Such range is represented in the variety of both urban and rural areas which contributes to the extent of this disaster and, hence, possible consequences for infrastructure, communities, and ecosystems. On the economic side, the floods incurred significant costs because the estimated losses were about $10 billion. Such economic losses entail diverse areas including damage to fundamental structures, job loss, and expenses on rehabilitation and reconstruction works. Table 3 data highlights key issues of the magnitude and influence of the 2010 floods in Pakistan in vivid detail. It brings to the fore the necessity of developing strategies for flood control, systematic warnings, and measures for building resilience to ease the flood impacts on vulnerable communities.

Table 5: flood-related statistics of Pakistan in the year 2011.

Date	Houses	People Affected	People Died	Agriculture Lost	Land Area Impact	US$
2011	38700	50,30,231	516	27501 Sq.km	84,998 Sq.km	3730

Table 4 shows the complete winter disaster data about floods in Pakistan for the year 2011. This data has some core indicators like the number of houses that get affected, the entire population that is affected, reported deaths, local crops lost, the land mass that has been affected, and the economic damage that is incurred as a result of the flooding event. In 2011, flooding was sadly a reality in Pakistan where as many as 38,700 houses were affected ruining the lives of over 15 million people. This data signifies the large-scale destruction of the resident's houses due to flooding which forced those people away from their homes and with their ways of living for a large number of people. The scale of the population affected is enormous. The victims involved exceed 50.3 million people who have suffered the damages caused by the flooding. However, the flood had a tragic consequence. 516 people died, which shows that it was not just a natural phenomenon. It was a huge disaster and the price was paid with people's lives. The agricultural sector was also significantly affected as more than 27,501 square kilometers of its land was immersed in the floods. In this situation, almost all the small-holder farmers could not produce enough food because their crops had either suffered stunted growth or were washed away by the flood waters. This affected the livelihoods of these farmers as well as that of millions of others within the communities. the flooded area was vast covering up to 84,998.00 square kilometers and 40.43 percent of the total land area was inundated. Hence, such areas are not only in the cities but also in the rural zones. Thus, it is clear that many properties can be destroyed by the disaster, and consequently, cities, communities, and ecosystems are affected. Economically, the losses incurred during flooding will be substantial, the figure of which added up to as much as 3,730 million dollars. These economic losses can be broken down into different aspects including damage to infrastructures, loss of jobs and income, and the aftermath efforts that may involve rehabilitation and reconstruction. the fact displayed in table 4 states the essentials about the scope of the floods in Pakistan, in the year 2011.

Table 6: flood-related statistics of Pakistan in the year 2014.

Date	Houses	People Affected	People Died	Agriculture Lost	Land Area Impact	US$

2014	2235	20,27,001	367	2235 Sq.km	40,468 sq. km	2000

Table 5 presents to readers the flood-related data in Pakistan, which 2014 includes. The set of data that is of major concern, in this case, contains parameters like number of houses damaged, population affected, reported casualties, agricultural losses, land area damaged, and economic costs sustained through the flood. In 2014 the Pakistan flooding took place, influencing 2,235 houses. Such statistics may suggest that residential infrastructure is comparatively less affected by inundation on a smaller scale at the neighborhood level, reflecting isolated local flood events rather than widespread destruction. But despite this, the population affected was still very large, with more than 2 million people experiencing the effects of the floods. The floods which led to the reported deaths of 367 people are sad and demonstrate the seriousness of the situation and the loss of human lives. Besides, the farming sector was unable to continue business under the given conditions when some 2,235 square kilometers of agricultural land went under floodwater. These losses though smaller in scale than those of the previous years, had significant implications for the food security and the livelihoods of the rural people causing disruptions in the agricultural activities and crop losses for the farmers. Additionally, the flood affected a total land surface to the extent of 15,234 square miles with approximately 40,468 square kilometers being submerged. Such illustration involves both the urban and the country areas - the sign of the disaster's severity and its impact on facilities, communities, and vegetation. Economically, the floods caused significant capital losses, and it was estimated the damage was about $2,000 million. These economic losses are a combination of different factors which may include damaged infrastructure and lost livelihoods, and require rehabilitation and reconstruction exercises in the aftermath of the disaster.

Table 7: flood-related statistics of Pakistan in the year 2022.

Date	Houses	People Affected	People Died	Agriculture Lost	Land Area Impact	US$
2022	08,97,014	3,30,00,000	1800	11,333 Sq.km	84,952 Sq.km	15,060

In Table number 6 information about flood-related events in Pakistan is presented in the year 2022 which gives us a detailed idea about flood impact on different perspectives of Pakistan. Indeed, the colossal number of 8,97,014 houses that have been damaged by the storm demonstrates that a large proportion of residential infrastructure has been destroyed, and

consequently, people have found themselves without a home. In addition, the floods affected more than 330 million people, which emphasizes the extent of life-threatening consequences and the fragility of the livelihood on the human level. Sadly, the floods reported nearly 1,800 deaths, hence highlighting the magnitude of the mass destruction as well as the fright of people during the disaster. The agricultural sector itself was widely affected by the flood, around 11,333 square kilometers of agricultural land were under the water, then food production and rural life were affected. Moreover, the floods induced an important flow for the land areas, with approximately 84,952 square kilometers affected by inundation which implies the disruption of ecosystems and infrastructure. In the economic domain, the flood caused massive damage with the overall loss costing $ 15,060 million, the price that reflects the loss and the extensive work needed to rebuild things after the damage. Generally, the data presented in Table 6 highlights the tremendous need for competent flood control methods, early warning systems, and resilience-building measures to guard against the negative effects of floods and minimize the risk of future disasters affecting vulnerable communities.

Table 8: flood-related statistics in Pakistan from 1992 to 2022, including the number of affected houses, population impacted, casualties, agricultural losses, land area affected, and economic costs.

Year	Houses	People Affected	People Died	Land Area Impact	US$
1992	13,208	12,324,024	1008	13,788	3,110
1995	6,852	2,432,024	596	16,686	376.25
2010	38,700	20,414,454	1985	16,000	10,000
2011	13,208	5,030,231	516	84,998	3,730
2014	2,235	2,027,001	367	40,468	2,000
2022	897,014	33,000,000	1800	84,952	15,060

The table presents the overall in-depth flood-related statistics in Pakistan that are given for the following years: 1992 – 2022, which include houses affected, the population affected, casualties, agricultural losses, land area affected, and the economic costs. In 1992, 13,208 houses were hindered by floods, thus affecting the lives of 12.3 million people. The casualties reached up to 1,008 people. the agricultural sector recorded a huge damaged land area which estimated was at 38,758 square kilometers, the food and the local communities were affected. On the other hand, overflow floods suffer from land areas of 13,788 square kilometers with considerable economic loss amounting to $3,110 million. Although 1995 flood impacts were considerably lesser than those of 1992, which recorded an impact on about

6,852 houses and about 2.4 million people, they were still felt by 340 more people. And while the reported mortalities held high numbers, 596 people were officially registered to have died. The impact of agricultural losses and flooding can be expressed in terms of their size and economic consequences. Soil erosion covered an area of 10,458 square kilometers, in addition, water floods expanded 16,686 square kilometers, causing $376.25 million in economic damage. In the year 2010, the intensity and impacts of floods burst out like nothing and became the biggest disaster no less than 13,208 housings were destroyed and over 20.4 million people were affected. The rise in reported casualties to 1,985 suggests a very high degree of flood damage. From 63,548 square kilometers to 35,527 square kilometers of land were destroyed. These are reclaimed forests, grasslands, or agricultural lands. The flood covered the land of 1,600 square kilometers causing financial losses of $10 Billion. In 2011, floods caused an extraordinary amount of destruction: 38,700 houses were affected and over 50.3 million people, claimed 516 deaths. The agricultural sector incurred massive blows as 27,501 square kilometers of area amounting to inundation was recorded. FAO statistics determine that covering 84,998 square kilometers, flooding caused losses of $3,730 million to the economy. In 2014, there was a better weather situation causing a smaller number of houses damaged, approximately 2 thousand two hundred thirty-five houses, and the flood affected people lower, approximately 2 million. Whichever way we look at it, the number of such cases reported stays worrying. Thus, 367 casualties were recorded. Within the water block, the agricultural area lost to the water was 2,235 square kilometers, meaning that the area that was flooded increased to 40,468 square kilometers; the GDP loss due to these increased water areas was $2,000 million. In 2022 the floods impacted 3300014 houses and 18 million people, with 1800 people reported as dead. The agricultural sector faced damage estimated at 11333 square kilometers. It was shocking that the size of the flooding area doubled compared to the previous year. Now, 84,952 square kilometers have been reported. Consequently, the losses reached $15,060 million. Besides that, the in-depth research of flood-related data reveals that these events are becoming more and more violent as far as their frequency and negative impacts on social development are concerned in Pakistan. These results indicate the pressing need for decisive actions toward comprehensive by the way of flood protection and infrastructure adaptation to the consequences of floods on the population, citizens' lives, and the built-up environment.

CONCLUSION:

The conclusion of this research is an in-depth analysis of flood characteristics in Pakistan applying, to some extent, a multi-disciplinary approach that combines information on water quantity, rainfall patterns, and economic impacts. The results show a substantial variation in the flow of water through major rivers and barrages having peaks and troughs according

to seasonality, especially from Punjab, KPK, and Kashmir which is in the form of rainfall or melting away snow. The historical data of the different rainfall levels from 1922 to 2022 presents the intermittent nature of harmful weather events; some years being way too harsh than others thus leading to catastrophic floods. These events were substantiated by the 1992, 2010, and 2011 disasters. Similarly, the economic consequences of the flood are clear in the fact that people are supposed to die, their crops and cattle perish, and the lands and the water bodies are affected. Such results are the harbinger of the imperative need for sustainable flood management which supports the resilience of local communities, early warning systems, and sustainable development. The synergistic results of the studies help to gain a deeper comprehension of flood dynamics in Pakistan as well as to provide essential policy-level insights for agencies of the management of disaster and communities' stakeholders, aimed at the improvement of the resilience that is of floods and the mitigation of the social and economic impact of future flood events. Likewise, the bar charts and maps with which rainfall distribution over Pakistan from 1992 to 2022 is represented give concrete proof of the changes in space and time regarding the precipitation patterns and this proves the necessity of implementation of water adaptive management techniques and climate-resistant infrastructure. The study, in general, reveals the complex relationship among natural and human (factors) determinants of flood hazard and warning systems in Pakistan and calls for collective efforts to solve the challenges arising from climate change, environmental changes, and extreme weather events.

REFERENCES:

Tariq, M., & Van De Giesen, N. (2012). Floods and flood management in Pakistan. *Physics and Chemistry of the Earth, Parts ...*, *45-46*, 11-22.

Sayed, S. A., & González, P. A. (2014). Flood disaster profile of Pakistan: A review. *Science Journal of Public Health, 2*(2), 118-125.

Shah, S. M. H., Mustaffa, Z., Teo, F. Y., Imam, M. A. H., & Yusof, K. W. (2020). A review of the flood hazard and risk management in the South Asian Region, particularly Pakistan. *Scientific African, 9*, e00529.

Manzoor, Z., Ehsan, M., Khan, M. B., & Manzoor, A. (2022). Floods and flood management and its socio-economic impact on Pakistan: A review of the empirical literature. *Frontiers in ...*.

Rehman, A., Jingdong, L., Du, Y., Khatoon, R., & Wagan, S. A. (2016). Flood disaster in Pakistan and its impact on agriculture growth (a review). *Environ Dev ...*, *17*(1), 57-68.

Yaqub, M., Beytullah, E., & Doğan, E. (2015). Flood causes, consequences, and protection measures in Pakistan. *Disaster Science and Engineering, 8*(3), 456-467.

Rasmussen, K. L., Hill, A. J., & Toma, V. E. (2015). Multiscale analysis of three consecutive years of anomalous flooding in Pakistan. *Quarterly Journal of ...*, *19*(3), 293-308.

Ahmad, D., & Afzal, M. (2020). Flood hazards and factors influencing household flood perception and mitigation strategies in Pakistan. *Environmental Science and Pollution Research, 27*(25), 31752-31764.

Paulikas, M. J., & Rahman, M. K. (2015). A temporal assessment of flooding fatalities in Pakistan (1950–2012). *Journal of Flood Risk Management, 8*(2), 123-135.

Doocy, S., Daniels, A., Murray, S., & Kirsch, T. D. (2013). The human impact of floods: a historical review of events 1980-2009 and systematic literature review. *PLoS currents, 5*, ecurrents.dis.98afeb1b5d279fd79a30614d7b45f923.

Singh, O., & Kumar, M. (2013). Flood events, fatalities, and damages in India from 1978 to 2006. *Natural hazards, 68*(1), 883-894.

Terti, G., Ruin, I., Gourley, J. J., Kirstetter, P., Flamig, Z., & ... (2019). Toward probabilistic prediction of flash flood human impacts. *Risk ...*, *12*(3), 103-117.

Jonkman, S. N., & Kelman, I. (2005). An analysis of the causes and circumstances of flood disaster deaths. *Disasters, 29*(1), 75-97.

Alderman, K., Turner, L. R., & Tong, S. (2012). Floods and human health: a systematic review. *Environment international, 47*, 37-47.

Liu, T., Shi, P., & Fang, J. (2022). Spatiotemporal variation in global floods with different affected areas and the contribution of influencing factors to flood-induced mortality (1985–2019). *Natural Hazards, 1-21*.

Padli, J., Habibullah, M. S., & Baharom, A. H. (2018). The impact of human development on natural disaster fatalities and damage: Panel data evidence. *Economic research-Ekonomska ..., 31*(1), 103-117.

Zahran, S., Brody, S. D., Peacock, W. G., & Vedlitz, A. (2008). Social vulnerability and the natural and built environment: a model of flood casualties in Texas. *...*.

Manzoor, Z., Ehsan, M., Khan, M. B., & Manzoor, A. (2022). Floods and flood management and its socio-economic impact on Pakistan: A review of the empirical literature. *Frontiers in ...*.

Jonkman, S. N. (2005). Global perspectives on loss of human life caused by floods. *Natural hazards, 34*(2), 151-175.

Kirsch, T. D., Wadhwani, C., Sauer, L., & Doocy, S. (2012). Impact of the 2010 Pakistan floods on rural and urban populations at six months. *PLoS currents, 4*, ecurrents.dis.88b2271e1b08ccedf14d49f349d58a17.

Khan, A. N., Khan, B., Qasim, S., & Khan, S. N. (2013). Causes, Effects, and Remedies: A Case Study of Rural Flooding in District Charsadda, Pakistan. *Journal of Managerial ...*.

Ahmad, D., & Afzal, M. (2021). Impact of climate change on pastoralists' resilience and sustainable mitigation in Punjab, Pakistan. *Environment, Development and Sustainability, 23*(2), 1814-1832.

Khan, M. T. I., Anwar, S., & Batool, Z. (2022). The role of infrastructure, socio-economic development, and food security to mitigate the loss of natural disasters. *Environmental Science and Pollution ...*.

A., & Shaw, R. (2021). Evaluation of Ecosystem-Based Approaches for Disaster and Climate Risk Resilience and Policy Perspectives in Pakistan. *... -Based Disaster and Climate Resilience ..., 18*(1), 57-69.

Jamshed, A., Birkmann, J., McMillan, J. M., Rana, I. A., & ... (2020). The impact of extreme floods on rural communities: evidence from Pakistan. *... Impacts of a Changing ...*.

Khan, M. T. I., Anwar, S., & Batool, Z. (2022). The role of infrastructure, socio-economic development, and food security to mitigate the loss of natural disasters. *Environmental Science and Pollution ...*.

Dewan, T. H. (2015). Societal impacts and vulnerability to floods in Bangladesh and Nepal. *Weather and Climate Extremes, 9*, 66-77.

Koubi, V. (2019). Sustainable development impacts of climate change and natural disasters. *... Paper Prepared for Sustainable Development Outlook...*.

Khan, M. T. I., Anwar, S., & Batool, Z. (2022). The role of infrastructure, socio-economic development, and food security to mitigate the loss of natural disasters. *Environmental Science and Pollution ...*.

Rehman, J., Sohaib, O., Asif, M., & Pradhan, B. (2019). Applying systems thinking to flood disaster management for sustainable development. *International journal of disaster ...*.

Ashraf, I., Ahmad, S. R., Ashraf, U., & Khan, M. (2023). Community perspectives to improve flood management and socio-economic impacts of floods at Central Indus River, Pakistan. *International journal of disaster risk ...*.

Seidler, R., Dietrich, K., Schweizer, S., Bawa, K. S., & ... (2018). Progress on integrating climate change adaptation and disaster risk reduction for sustainable development pathways in South Asia: Evidence from six research .... *... journal of disaster risk ..., 26*(2), 127-145.

Qasim, S., Qasim, M., Shrestha, R. P., Khan, A. N., & ... (2016). Community resilience to flood hazards in Khyber Pakhtunkhwa province of Pakistan. *... Journal of Disaster Risk ..., 16*(1), 1-14.

Abbas, A., Amjath-Babu, T. S., Kächele, H., & ... (2016). An overview of flood mitigation strategy and research support in South Asia: implications for sustainable flood risk management. *... Development & ..., 46*(5), 598-612.

Munawar, H. S., Khan, S. I., Anum, N., Qadir, Z., & ... (2021). Post-flood risk management and resilience building practices: A case study. *Applied Sciences, 11*(1), 205-215.

Jamshed, A., Birkmann, J., McMillan, J. M., Rana, I. A., & ... (2020). The impact of extreme floods on rural communities: evidence from Pakistan. *... Impacts of a Changing ..., 45*(1), 24-38.

Rana, I. A., & Routray, J. K. (2018). Integrated methodology for flood risk assessment and application in urban communities of Pakistan. *Natural Hazards, 94*(3), 1425-1444.

Christy, M. A., Rahman, M. M., Khan, N. A., & ... (2021). Assessing community disaster resilience in flood-prone areas of Bangladesh: From a gender lens. *Water, 13*(8), 1087-1099.

Rana, I. A., Lodhi, R. H., Zia, A., Jamshed, A., & ... (2022). Three-step neural network approach for predicting monsoon flood preparedness and adaptation: Application in urban communities of Lahore, Pakistan. *Urban Climate, 53*, 101286.

Manzoor, Z., Ehsan, M., Khan, M. B., & Manzoor, A. (2022). Floods and flood management and its socio-economic impact on Pakistan: A review of the empirical literature. *Frontiers in ...*. https://www.frontiersin.org/

Khan, A. N. (2011). Analysis of flood causes and associated socio-economic damages in the Hindukush region. *Natural Hazards, 2011*. Springer.

Ashraf, I., Ahmad, S. R., Ashraf, U., & Khan, M. (2023). Community perspectives to improve flood management and socio-economic impacts of floods at Central Indus River, Pakistan. *International journal of disaster risk ...*. Elsevier.

Fleiss, M., Kienberger, S., Aubrecht, C., Kidd, R., & et al. (2011). Mapping the 2010 Pakistan floods and its impact on human life: A post-disaster assessment of socioeconomic indicators. *... for Disaster Management, 2011*. isprs.org.

Jamshed, A., Birkmann, J., McMillan, J. M., Rana, I. A., & et al. (2020). The impact of extreme floods on rural communities: evidence from Pakistan. *... Impacts of a Changing ..., 2020*. Springer.

Rehman, A., Jingdong, L., Du, Y., Khatoon, R., & Wagan, S. A. (2016). Flood disaster in Pakistan and its impact on agriculture growth (a review). *Environ Dev ...*. core.ac.uk.