Investigating the Significance of Modern Technology-based Flood Forecasting and Anticipation: A Case Study of National Emergency Operation Centre

By

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A thesis submitted to the National University of Sciences and Technology, Islamabad,

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DEDICATION

This thesis is dedicated to my beloved parents, whose unwavering love, support, and prayers have been my greatest source of strength. Without your encouragement and sacrifices, this achievement would not have been possible.

I also dedicate this work to my teachers and mentors, whose wisdom and guidance have shaped me into the person I am today.

Also, to all those who believed in me, this work is a reflection of your trust and confidence in my abilities.

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ABSTRACT

Flood forecasting and anticipation are becoming integral parts of disaster risk reduction because of the growing frequency and intensity of floods, which are consequences of climate change and urbanization. Pakistan, particularly vulnerable to climate-induced disasters, has faced devastating flood events, such as those in 2010 and 2022, which caused widespread damage to infrastructure, agriculture, and human lives. This research study attempts to investigate the role of modern technology-based flood forecasting in improving preparedness and response mechanisms, with specific attention to the NEOC of Pakistan. This research is a comprehensive review of current policies and strategies for flood management in Pakistan, identifying their gaps, challenges, and opportunities for improvement. This research has exemplified the policy in flood management and its incorporation with modern technology, such as remote sensing, GIS, hydrological models, and artificial intelligence, which could be devised for better frameworks of flood forecasting and overall management. The research also identifies some of the best practices in the area of flood management around the globe, which give an insight into community-led initiatives and modern technologies applied towards resilient infrastructures and effective flood response. It provides actionable recommendations to policymakers for adopting a more integrated, equitable, and technology-driven approach toward better flood management in order to enhance disaster preparedness in the country and reduce the socio-economic impact on the vulnerable population.

CHAPTER 1: INTRODUCTION

1.1. Background

Flood forecasting and anticipation have become critical in modern societies due to the increasing frequency and severity of flood events, which are often exacerbated by climate change and urbanization. As humankind has progressed, climate change has emerged as one of our day's most significant and intricate global issues. In many cases, the word "climate change" refers to a long-term shift in weather patterns and temperature patterns in a specific place (Shahid & Ashraf, 2021). Since climate change is a worldwide problem, every state is equally susceptible to its consequences depending on its location, degree of development, and quantity of greenhouse gas emissions. With the rise in global temperature, various weather patterns and geographical circumstances emerged. Global warming, climate change, and temperature changes have directly affected snow, rivers, lake ice, sea ice, and glaciers leading to increased flood risks due to altered weather patterns and geographical circumstances (Micheal, 2023). Increased population density and the development of infrastructure are results of urbanization, the conversion of rural areas into urban areas due to industrialization, migration, and economic possibilities. Urbanization changes natural landscapes and drainage systems, which increases risk of flooding even as it spurs economic expansion. Urbanization increases the risk of floods in flood plain areas due to greater peak flow and volume as well as a shorter time to peak (Suriya & Mudgal, 2012). The ability of land to absorb rainwater is decreased when natural water-absorbing surfaces are replaced with impervious materials like concrete. This increases surface runoff and may overwhelm drainage systems, resulting in urban flooding. Additionally, the loss of vegetation brought on by urban expansion exacerbates soil erosion and diminishes the ability of nature to mitigate floods.

Advancement in technology is quickly replacing, or at least supplementing, traditional flood prediction approaches that mainly depended on historical data and meteorological observations. Current methods use remote sensing, real-time data analytics, satellite imaging, and advanced computer models to produce forecasts that are more precise and timelier (Munawar et al., 2022).

Satellite imagery allows for the monitoring of large geographic areas and the detection of changes in water levels and land conditions that may indicate impending floods. Remote sensing technologies, on the other hand, enable the collection of data from inaccessible or hazardous locations, providing critical information without putting human lives at risk. Real-time data analytics process vast amounts of data instantaneously, ensuring that forecasts are based on the most current information available. Sophisticated computer models simulate various flood scenarios, taking into account topographical features, weather patterns, and water flow dynamics to predict where and when floods are likely to occur.

By integrating these technologies, communities can better prepare for potential flooding, ultimately reducing the impact on lives, property, and the environment. Early warning systems can be put in place, evacuation plans can be developed and refined, and resources can be allocated more efficiently (Lammers et al., 2021; Sadiq et al., 2022). Furthermore, these advanced systems can help policymakers and urban planners design more resilient infrastructure and implement sustainable water management practices.

Flood management has evolved significantly, shifting from simple water channeling and diversion techniques to advanced, technology-driven solutions. Effective flood modeling and forecasting are now crucial for managing and preparing for extreme flood events. According to the international disaster database, flooding is the most frequent natural hazard globally, accounting for 39% of all natural disasters since 2000 and affecting over 94 million people annually (Wu, et al., 2020). The World Meteorological Organization (WMO) highlights that while economic losses from flooding have increased over the past 50 years, advancements in monitoring and forecasting hydrometeorological hazards have significantly reduced the loss of life (WMO, 2015).

Pakistan is now among the top 20 countries in the world in terms of climate change sensitivity, according to national and international environmental specialists. The reasons for this can be attributed to various variables, including geographical factors, deforestation, carbon emissions resulting from industrialization, increasing urbanization, resource scarcity, and socioeconomic situations (Farooqi et al., 2005). Pakistan is a densely populated country that relies heavily on agriculture and has few resources. Pakistan is currently experiencing significant problems, including large floods, droughts, and prolonged and harsh heat waves that cause fatalities, force people to flee their homes, and destroy infrastructure and economies. Pakistan is also vulnerable to climate change. In 2010, the nation had one of the most lethal calamities, impacting over 20 million individuals and causing severe harm to animals, infrastructure, and agriculture. Countless individuals were reported as missing from their residences, while over 1700 people tragically died.

The 2010 floods resulted in the destruction or damage of more than 1.7 million dwellings, as well as numerous crops and agricultural land (power, 2010). Later in 2022, Pakistan experienced yet another disastrous flood, but this time it affected a greater number of people than earlier. Approximately 33 million individuals have been affected, and roughly one-third of the countries have experienced flooding. The incident resulted in the loss of 1,400 people and had a significant impact on 3% of Pakistan's GDP. Railway operations experienced unprecedented devastation, with daily losses of Rs. 90 million, and about 13,000 km of roads and highways were devastated (Gov, 2022).

In response to the challenges posed by climate change, the government of Pakistan has initiated a National Adaptation Plan and a National Climate Change Strategy. These initiatives aim to address the impacts of climate change through the implementation of many techniques and countermeasures. In addition, the Pakistani government has established the National Disaster Management Authority (NDMA) to document past disasters and develop strategies to mitigate future disasters. In order to increase public awareness regarding the importance of trees, the Pakistani government took the initiative to close down its coal-fired power plants and launched a campaign named "Ten Billion Trees Tsunami." Notwithstanding these endeavours, Pakistan still faces significant challenges in tackling the consequences of climate change due to insufficient finance, limited institutional capacity, and a lack of political determination. The administration has underscored the importance of international support and collaboration in this domain, although the nation remains committed to tackling climate change.

Pakistan is currently dealing with a disastrous situation due to the floods, which has led to a substantial worsening in the country's economy. Considering that agriculture is the largest portion of Pakistan's Gross Domestic Product (GDP), the floods caused considerable damage to the country's crops and livestock. Due to the shortage of food inflation and poverty increased (Zaman, 2017).

Climate change is thus leading to a decline in both the quantity and quality of resources. Consequently, there will be a rise in interstate movement along with issues related to water and food security. This will result in a domino effect that will ultimately compromise the security of our region. As a result, this issue will not only have implications for the environment, but it will also impact national security and politics. The government's inadequate crisis management strategies, particularly in Sindh, exacerbate the challenges of addressing the flood-affected regions, which are already grappling with political and economic instability (Ishaque et al., 2022).

The government of Pakistan collaborated with the Asian Development Bank and the United Nations to create a document called "Pakistan Floods 2022: Post Disaster Needs Assessment Report." This study examined the calamity caused by the 2022 floods and analysed its underlying factors. According to this article, the intense monsoon rains adversely affected over 6 million people and resulted in the displacement of nearly 2 million residents from their homes. In 2022, Pakistan experienced one of its most severe floods, which was attributed to climate change (Gov, 2022). The report also highlighted the detrimental impact on livestock agriculture and infrastructure. This report also addresses the challenges that the government faces in managing flood recovery and restoration. The 2020 flood assessment study provides a comprehensive examination of the various elements that contributed to the 2020 flood, as well as its resulting impacts. Ultimately, the paper highlights the importance of constructing catastrophe resilience to effectively manage potential hazards in the future.

1.2. Problem Statement

Pakistan is currently grappling with severe issues such as scorching heat waves, colossal floods, and droughts that have resulted in loss of life, displacement of people, and significant damage to economy and infrastructure. Floods in Pakistan have a devastating impact on the lives of people, often resulting in loss of life and significant destruction of property and infrastructure, particularly in isolated areas with limited access to resources and aid.

Despite significant advancements in flood forecasting technology, achieving universally reliable and accurate predictions remains challenging, particularly in regions with limited financial and technical resources like Pakistan. Traditional flood management policies and strategies often fall short in addressing the rapidly evolving environmental conditions. This shortfall results in inadequate preparation and response measures, leaving vulnerable populations at risk. Modern technology-based systems offer promising solutions but introduce complexities such as data quality issues, accessibility challenges, and the need for specialized technical expertise. The technological disparity between developed and developing regions further exacerbates these issues, limiting the benefits of advanced forecasting methods to select few. To enhance flood resilience and mitigate socio-economic impacts, there is a pressing need to assess and integrate advance technologies in a manner that is both effective and equitable.

1.3. Research Objectives

- To review the existing flood management policies and strategies in Pakistan to identify challenges and gaps in flood management
- To review innovative flood management approaches, including modern technologies, community-based initiatives, and best practices from around the globe
- To investigate the role of NEOC in flood hazard assessment in Pakistan

1.4. Research Questions

- What are the existing flood management policies and strategies in Pakistan, and what challenges and gaps exist in flood management?
- What innovative flood management approaches, including modern technologies, community-based initiatives, and best practices from around the globe, can be reviewed?
- What is the role of NEOC in flood hazard assessment in Pakistan?

1.5. Significance of study

The significance of this study lies in its comprehensive approach to addressing the multifaceted challenges of flood management in Pakistan. This study will contribute to the body of knowledge on flood risk management by identifying key gaps in current practices and policy frameworks. Understanding the role of community-based initiatives and integrating best practices from across the globe will offer valuable insights into sustainable and inclusive flood management strategies. By focusing on the National Emergency Operation Centre (NEOC), the study will also provide specific, actionable recommendations by systematically evaluating modern flood forecasting methodologies that aims to provide a clear understanding of their respective efficacies and limitations. This research will serve as a crucial resource for policymakers, urban planners, and disaster management authorities, empowering them to develop more resilient infrastructure and implement effective, equitable flood management practices.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

Flooding is a highly destructive natural phenomenon that causes extensive harm to infrastructure, forces communities to relocate, and leads to substantial economic setbacks on a global scale. Precise and prompt flood forecasting is essential in reducing these effects, allowing authorities to adequately plan and respond. Historically, flood forecasting depended on observational data and basic predictive models, which frequently lacked accuracy and immediate reaction. Nevertheless, recent technological breakthroughs have completely transformed this subject, providing more advanced and precise ways for forecasting. Flood forecasting in modern times relies on a range of sophisticated technologies and methods, such as remote sensing, Geographic Information Systems (GIS), and hydrological and meteorological models. These technologies facilitate a thorough comprehension of hydrological processes by amalgamating copious volumes of data from diverse sources, including satellite photography, radar, and ground-based sensors. The integration of machine learning and artificial intelligence significantly improves the ability to analyze intricate datasets, accurately forecast flood events, and evaluate the potential consequences on susceptible regions.

The literature review will examine the importance of modern technology in predicting and anticipating floods, with a specific emphasis on how they are used at the National Emergency Operation Centre (NEOC). The NEOC serves as a crucial hub for disaster management, playing a critical role in coordinating responses to flood catastrophes. The assessment will assess the integration of these technologies by the NEOC to improve its operational efficiency, by delivering prompt alerts and enabling appropriate allocation of resources in emergencies.

This inquiry will examine the development of flood-predicting technology, its practical uses in different parts of the world, and the specific methods used by the NEOC. Additionally, it will address the difficulties linked to the adoption of these technologies, encompassing technological, logistical, and ethical factors. In addition, the literature evaluation will analyze existing research to identify areas where more exploration is needed. The goal is to contribute to the continuous enhancement of flood forecasting and response systems.

This literature review establishes the foundation for a thorough examination of how modern technology improves flood predicting and anticipation. This review evaluates the current knowledge to establish a basis for comprehending how technological advancements have significantly influenced flood management practices. It specifically focuses on the efforts of the NEOC to protect communities and infrastructure from the destructive consequences of flooding.

2.2. Floods

The increase in the occurrence of storms and flooding in recent years can be attributed to global warming and the growing urbanization (Miller & Hutchins, 2017; Vaughan et al., 2019). According to Hui et al. (2018), the phenomenon of global warming has led to a substantial rise in the average temperature of the Earth, thereby causing noteworthy alterations in the climate. The correlation between global warming and floods can be elucidated by the fact that warmer air has a higher capacity to retain moisture (Beck & Mahony, 2018). Global warming leads to elevated air temperature, resulting in substantial precipitation that ultimately leads to flooding (Kaufmann et al., 2016). According to Zheng et al. (2019), if we don't reduce greenhouse gas emissions, global warming is expected to cause a 40% increase in precipitation during the usual periods of heavy rainfall. In addition, even if the trends of global warming were reversed, it is still probable that the amount of precipitation will stay 20% greater by the end of this century, as indicated by studies conducted by (Tu et al., 2024). Consequently, the frequency of flood emergencies is expected to rise in the future. As a result, it is imperative to prioritize flood disaster planning and management.

Modern society is still struggling to determine the most efficient methods for addressing instances of flooding (Dolman et al., 2018). Undeniably, every country in the globe has encountered the consequences of flooding situations, regardless of their varying levels of prosperity (Al-Amin et al., 2019). The 2017 flooding in Houston, Texas, demonstrated the perilous and unmanageable nature of floods, as well as the complexity involved in their management throughout the event (Isaranuwatchai et al., 2017). Hurricane Harvey resulted in the most significant occurrence of heavy rainfall from a tropical cyclone in the history of the United States. This led to extensive flooding (Blake and Zelinsky, 2018).

Despite the US having a robust flood management system, the aftermath of the 20 cm of rainfall over a 24-hour period demonstrated the challenges in effectively addressing the situation (Blake and Zelinsky, 2018). Floods have had a negative worldwide impact.

Annually, floods result in the deaths of around 25,000 people worldwide (UNU, 2004). This peril is expected to escalate with the ongoing progression of climate change (Torzhkov et al., 2019). Projections from many studies (Paltan et al., 2017; Zhang & Soden, 2019) suggest that climate change will not cause any consistent changes or variations in the amount of annual rainfall from now until 2080. The implications of these studies suggest that areas with high levels of precipitation will persist in experiencing such conditions, hence complicating efforts to address the issue of floods in the future

Many nations are still grappling with the challenge of effectively managing floods as they consider strategies to address climate change and the impacts of urbanization (Wu et al., 2024). It is worth mentioning that the risk of flooding is relatively easier to handle compared to other natural disasters. The key lies in implementing efficient systems and forming strong partnerships to reduce the risk (Berndtsson et al., 2019; Wingfield et al., 2019). In contrast to other natural crises, scientists can make precise predictions regarding the location, probability, behavior, and consequences of floods (Rehman et al., 2019; Wingfield et al., 2019). In the United Kingdom, the Environment Agency (EA), Natural Resources Wales (NRW), and Scottish Environment Protection Agency (SEPA) are responsible for continuously monitoring rainfall patterns, river levels, and the condition of the sea to forecast the likelihood of flooding. They then issue early warnings accordingly (Met Office, 2020). Hence, society has limited justifications for failing to handle flood dangers responsibly. An important issue emerges when the probability of an event happening is uncertain and when there is little time available before acting in response.

2.3. Types of Floods

Comprehending the many categories of floods is crucial for the creation, advancement, and execution of flood control methods. According to (Vojtek & Vojteková, 2016), a flood is characterized by the discharge of a large volume of water that exceeds the capacity of the drainage system. There are numerous sorts of floods that are described based on their occurrences, the damage they do, and how they are forecasted. These floods are related with various phenomena. The primary categories of flooding are coastal flooding caused by storm surges, fluvial flooding caused by rivers, pluvial flooding caused by surface and flash floods, and groundwater flooding. The magnitude of the floods is contingent upon the strength of the rainfall, the geographical spread of the rainfall, the terrain, and the surface conditions (Tramblay et al., 2011).

2.3.1. Coastal flooding

A storm surge, which is primarily responsible for coastal flooding, refers to an atypical increase in seawater levels resulting from low-pressure storm systems. It is quantified by measuring the height of the saltwater above the expected tide levels (Prime, 2018). Tides frequently result from the movement of seawater towards the shoreline due to the force of a storm wind (Jalili Pirani and Najafi, 2020). The storm surge at a certain place is influenced by factors such as the orientation of the shoreline relative to the storm's path, the speed, size, and strength of the storm (Fernández-Montblanc et al., 2019). This flood variant is distinguished by the inundation of water onto areas with low elevation, resulting in catastrophic loss of life and extensive damage to property (Duncombe, 2019). Coastal floods are typically categorized into three levels: small, moderate, and major (Takagi et al., 2016). A minor coastal flood results in a small degree of beach erosion, but no significant damage is anticipated (Takagi et al., 2016). Kwari et al. (2015) state that the moderate kind is characterized by a significant level of beach erosion and some damage to homes. A significant coastal flood presents a grave danger to both human life and property, resulting in extensive beach erosion, widespread road flooding, and structural destruction (Sobel, 2014; Kirezci et al., 2020). In a study conducted by (Hinkel et al., 2014), it was anticipated that in the 21st century, a minimum of 0.2-4.6% of the world's population will be affected by flooding due to the projected increase in sea levels of 25-123 cm. If the sea level rise is not mitigated, it will lead to a loss of between 0.3-9.3% of the world gross domestic product, which is unlikely to be accepted. According to the study, the projected cost of building and maintaining coastal dikes worldwide in the 21st century might range from $12 to $71 billion dollars (Hinkel et al., 2014). Figure 2.3.1 demonstrates that Hurricane Sandy resulted in a substantial coastal flood, leading to extensive property damage along the Jersey shore in October 2012.

Figure 2.3.1: *Coastal flood damage caused by Hurricane Sandy (Real Climate., 2014)*

2.3.2. Fluvial flooding

This form of flooding occurs when there is an abundance of rainfall over a prolonged period, resulting in a river above its normal capacity (Nace, 2017). Nabangchang et al. (2015) state that floods can result from severe snowmelt or ice jams, causing extensive damage when the overflowing river affects smaller rivers downstream. The flood has the potential to result in the rupture of dams and dikes, leading to the inundation of nearby areas (Nace, 2017). Overbank flooding, the primary kind of fluvial flooding, can occur in rivers of any size. It is caused by the rising water level that exceeds the capacity of the river channel, resulting in water spilling its banks (Cook et al., 2018). According to (Pommeranz & Steininger, 2019), precipitation alone is insufficient to trigger river floods. Alternatively, if it weren't for the riverbanks, the rainwater that enters the river would just run downstream into the sea without causing any erosion or damage. During precipitation, a portion of the water descends directly into the river, while another portion is deposited onto the surface of the land. Continued rainfall saturates the soil, preventing it from absorbing additional water from the surface, resulting in surface runoff. Runoffs are directed into streams and then flow into the river, depending on the gradient of the land surface. Figure 2.3.2 depicts an instance where intense precipitation resulted in the overflow of the Rivers Severn and Avon, as well as the inundation of Tewkesbury Abbey's front range and adjacent residential buildings in 2020.

Figure 2.3.2: *2020, 2019 and 2007 flooding of Tewkesbury, Gloucestershire (Wu et al., 2024)*

2.3.3. Pluvial flooding

Pluvial flooding occurs when intense rainfall exceeds the capacity of both natural and man-made drainage systems in a small area (Bubeck & Thieken, 2018). (Wu et al., 2024) and (Bubeck & Thieken, 2018) have found that pluvial flooding primarily occurs in metropolitan areas. Pluvial flooding is defined by the authors as the situation where the amount of rainfall surpasses the combined ability of both natural and man-made drainage systems to handle it. Urban areas mostly possess constructed drainage systems that are susceptible to flooding. Urban drainage systems may be overwhelmed by excessive rainfall due to their limited capacity to store and convey water (Pommeranz & Steininger, 2019). Conversely, inadequate drainage systems in urban areas can lead to flooding, particularly when some drainage systems are blocked due to urban waste (Wu et al., 2024). There is a widespread misunderstanding that individuals residing in proximity to rivers and other bodies of water are the most susceptible to flooding. Pluvial floods suggest the opposite. These floods occur in locations that are distant from bodies of water (Netzel et al., 2021). There are two prevalent types:

2.3.4. Surface water floods

Surface water flood is prevalent in urban areas where heavy rainfall overwhelms the urban drainage infrastructure. (Noy et al., 2021) contend that the urban drainage system might reach a state of saturation when it becomes overloaded, resulting in the overflow of water into streets and adjacent structures. In addition to heavy rainfall, the construction of the urban drainage system, particularly the tunnels, is a significant factor contributing to the obstruction. The majority of the internal surfaces of urban drainage systems are constructed using concrete and coated with cement in order to facilitate a smoother flow of water (Jha et al., 2012). According to (McGrane, 2016), the alteration of ecosystems by humans to facilitate the construction of buildings and facilities affects the processes that generate runoff and the paths that water flows through. This has a significant impact on the limits of catchment areas and the pathways that water drains through. Figure 1.3 demonstrates that the intense rainfall in the UK during the summer of 2007 resulted in widespread pluvial flooding. Pluvial flooding occurs in areas where there is an abundance of clay-rich bedrock and/or topsoil. In the last ten years, the UK Environment Agency has incorporated clay-rich ground into specific flood-prone locations (Archer et al., 2019).

2.3.5. Flash floods

Precipitation originates from rainfall in elevated rural or mountainous regions. Hillsides that have seen recent forest fires are frequently responsible for pluvial floods, just like suburban areas situated on the hillside (Rözer et al., 2016). Over the past three decades, the United Kingdom has experienced numerous destructive flash floods in narrow, rocky valleys, including Boscastle in 2004 and Calderdale in 1989 and 2012 (Doe, 2015).

Figure 2.3.3: *The 2007 UK Summer floods (Whitelaw, 2009)*

The efficiency of urban drainage systems is closely linked to a country's level of economic growth. Cities characterized by a high population density are prone to having inadequate drainage systems in the presence of inappropriate waste management measures (Ferronato & Torretta, 2019). There are specialized programs specifically developed to regulate the flow of water in urban areas. A Sustainable Urban Drainage System (SUDS) is an engineered system specifically designed to control and regulate surface drainage in urban environments (Hoang & Fenner, 2016). Typically, different types of terrain, especially metropolitan settings, possess inherent mechanisms for directing the flow of surface water. Nevertheless, the process of constructing structures and modifying the typically absorbent urban soil surface hinders natural drainage to a large extent (Ellis & Viavattene, 2014). In addition, agricultural activities near metropolitan areas have a substantial impact on the topography of the environment. The degree of infrastructural development directly influences the intricacy and structure of the Sustainable Urban Drainage Systems (SUDS) (Koop and van Leeuwen, 2016).

2.4. Global risks from flooding

Risks and consequences associated with flooding are often classified as either *direct* or *indirect*, and *tangible* or *intangible*, respectively. According to Rothkrantz and Fitrianie (2018), ***direct consequences*** of flooding have a direct effect on the area and time of the flood event Floods result in substantial losses that may be readily measured or quantified. The primary outcomes of floods are fatalities, property damage, casualties, forced migration, animal loss, and crop destruction (Rothkrantz and Fitriane, 2018). These factors can be readily verified or measured due to their observable nature. Consequently, it may be deduced that floods have measurable outcomes (Armaroli et al., 2019). The quantitative assessment of the casualties, property damage, and agricultural losses resulting from the disaster can be determined using numerical measurements (Hudson et al., 2019). (Pregnolato et al., 2017) state that direct flood hazards frequently impact both people and the wider community. Often, floods result in the devastation of communication and transport infrastructure, impacting both the community and the government (Armaroli et al., 2019). According to (Munawar et al., 2022), the total death toll from floods and other meteorological disasters since 1995 exceeds 600,000. (Jonkman et al., 2009) utilized mathematical modeling and spatial mapping approaches to examine the correlation between mortality and flooding following Hurricane Katrina in New Orleans, USA. The study examined 1118 deaths and discovered that almost one-third of the 771 deaths occurred in locations outside of flooded areas, such as hospitals or shelters within flooded areas. These deaths were linked to the negative impact on public health following the flood. The flood resulted in two-thirds of deaths, primarily owing to the direct physical effect, with most fatalities occurring because of drowning. Many of the casualties are members of the majority of individuals in the older age groups, nearly sixty percent of whom were over the age of 65, were represented in the studies conducted by (Jonkman et al., 2009; Miao, 2019). The impacts of floods on lives and injuries can be categorized as socioeconomic in the following section.

On the other hand, ***indirect consequences*** are losses that do not incur immediately after the disaster; but they are primarily associated with the direct consequences (Nicklin et al., 2019). For example, friends and relatives are impacted by the loss of the lives of their loved ones. The disruption of electrical and communication infrastructure leads to the unavailability of services, particularly in today's technologically advanced world. The standing water that accumulates during floods might serve as a favorable environment for the proliferation of some diseases, such as malaria and typhoid (Saulnier et al., 2019). Reconstructing areas affected by floods imposes an extra economic burden on the government (Zeng et al., 2019). Consequently, the resources that were originally allocated for important projects are redirected into emergency management. (Talbot et al., 2018) argue that typically, only the immediate and conspicuous consequences of the flood are commonly documented, whereas there are several secondary effects. The study specifically examined the effects of floods on aquatic ecosystems. The identified areas encompass support services such as the creation and initial development of soil, as well as the regulation of water, diseases, and water quality.

They also include service provision in the form of drinking water and food supply, as well as cultural values such as recreation, tourism, and aesthetic appreciation (Talbot et al., 2018).

Tangible refers to the effects that can be monetized, while ***intangible consequences*** are those flood effects that are more difficult to quantify or monetize (Andrade & Szlafsztein, 2018). According to UNISDR (2017), severe floods have substantial economic consequences that can extend beyond the immediate flood-affected region. Therefore, the primary hazards associated with flooding are the devastation of property (including buildings and infrastructure such as roads and electricity) and the loss of both human and animal lives. The monetary value of the damaged property, including buildings and washed away autos, can be quantified (Allaire, 2018). In addition, there are intangible dangers associated with direct loss of lives, both human and non-human, in the impacted areas (Frazier et al., 2020). These risks are distinct from direct tangible ones in that their repercussions cannot be quantified or assigned a clear monetary value due to the absence of a precise measure or metric. The concept of "market value" is used to quantify the worth of lives lost or damages incurred during a flood. This is regarded the most significant and permanent impact on society caused by floods (Frongia et al., 2016). Physical injuries, ecosystem degradation, and cultural heritage destruction are additional forms of direct intangible consequences that are considered to be less severe in comparison to the loss of human life (Bubeck & Thieken, 2018). An instance of a severe flood occurrence that led to significant loss of life is the Venezuela flood (1999), which was caused by copious rainfall. The rainfall was accompanied by mudslides in the "Sierra de Avila" region, resulting in the loss of around 30,000 lives (Bubeck & Thieken, 2018). Consequently, flooding causes substantial harm to both individuals and property in the areas that are impacted. Table 1 displays a compilation of the 10 most fatal flood incidents and the corresponding total losses incurred since 1980, sourced from the EM-DAT database.

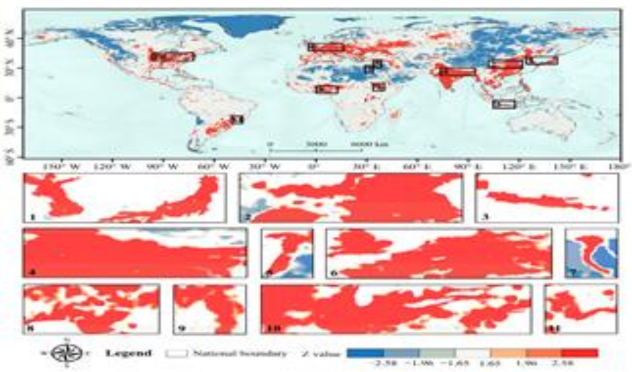

Figure 2.4.1: *Spatial Distribution from Global Risk from Flooding (Bubeck & Thieken, 2018)*

Table 1: *The 10 deadliest flood events between 1980 and 2020 (EM-DAT, 2020)*

Rank	**Country**	**Year**	**Total Deaths**	**Total Damages ('000 US$)**
1	Venezuela	1999	30000	3160000
2	China	1980	6200	160000
3	India	2013	6054	1100000
4	China	1998	3656	30000000
5	China	1996	2775	12600000
6	Haiti	2004	2665	
7	Bangladesh	1988	2379	2137000
8	Somalia	1997	2311	
9	Bangladesh	1987	2055	330000
10	India	1994	2001	175000

From the above table, it is clear that Asia experienced the highest number of fatalities resulting from flooding, accounting for 67% of the total. Subsequently, America experiences deaths at a rate of 22%, whereas Africa has a lower rate of 9%. It is important to mention that in industrialized regions like Europe, the number of human casualties is relatively low compared to other regions. This is a result of the deployment of highly efficient and effective disaster management systems and the increased capability of early warning systems.

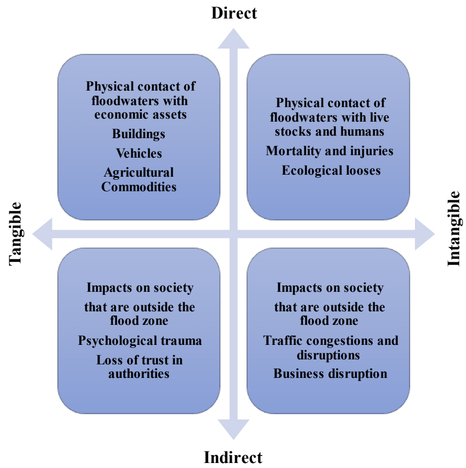

Figure 2.4.2: *Summarizes the typology of societal flood impacts and examples for each category (Andrade & Szlafsztein, 2018)*

2.4.1. Socio-Economic Flood Vulnerability Around the World

The flooding has significant socio-economic consequences for the residents of the affected areas. According to a study conducted by (Hammond et al., 2015), the primary consequence of floods is the significant loss of human lives and property. The accurate assessment of the worth of the lost assets is determined by empirical assessments of the building and content losses. An illustrative example occurred in 2010, when Pakistan encountered widespread and catastrophic floods in the Indus River basin. The flooding had a severe impact on 20 million people, resulting in the loss of 1400 lives (S. M. H. Shah et al., 2020). China has also had negative impacts from river flooding and landslides. In 1998, the nation encountered a flood event that resulted in a cumulative mortality toll of 3,656. In 2016, floods caused a total of 449 deaths (Lyu et al., 2018). The case of China and Pakistan exemplifies the magnitude of human casualties resulting from the issue of flooding. Having efficient flood management systems is crucial worldwide to eliminate the loss of life (Gilissen et al., 2016). The loss of life and property are immediate consequences and are frequently accompanied by the devastation of crops and livestock. For example, the floods that occurred in Queensland, Australia in 2011 resulted in the death of numerous animals as their habitats were submerged by water, and cattle was unable to move to higher ground in a timely manner. Consequently, they have been eroded (Keoduangsine et al., 2014; Keogh et al., 2011). Another notable loss is the decline in biodiversity of wildlife. The June 2013 floods in Alberta caused four fatalities, while the 2015 floods in Myanmar caused the displacement of 1.6 million individuals. The floods were predicted to have incurred a cost equivalent to 3.1% of the country's GDP for the fiscal year 2014/2015. According to the World Bank (2019), individuals living in the impacted regions of Chin, Myanmar, have reported average losses of approximately $115 per person. Additional socioeconomic repercussions encompass flood-induced catastrophes, as well as the incapacity to engage in employment and fulfill other economic endeavors. In their study, (Dolman et al., 2018) stated that the government estimates the socio-economic losses to Rio Branco to be $98 million. Nevertheless, employing an alternative model, the investigation revealed that the losses might potentially reach a staggering sum of $200 million. Furthermore, it is worth noting that floods transpire nearly every year. In addition, these risks frequently coincide with severe health consequences such as drowning, hypothermia, and electrical damage, resulting in substantial health detriments for families (Shabir, 2013). Table 1.2 displays the expenses incurred due to flooding in different nations over the year 2019.

Table 2: *The costs of flooding in various countries during 2019 (Podlaha et al., 2020)*

Date (year 2019)	**Country**	**Deaths**	**Structure/ Claims**	**Economic Losses (USD)**	**Date (year 2019)**
09-31 Jul	Bangladesh	210	584,000+	75+ million	09-31 Jul
16-18 Mar	Indonesia	194	3,000+	103+ million	16-18 Mar
07 Jul-23 Aug	Pakistan	143	4,000+	75+ million	07 Jul-23 Aug
22-24 Apr	South Africa	87	7,500+	100+ million	22-24 Apr
28 Jun-04 Jul	India	77	25,000+	100+ million	28 Jun-04 Jul
26 Dec	Colombia	18	2,000+	15+ million	26 Dec
27-29 Jan	Saudi Arabia	12	2,000+	25+ million	27-29 Jan
11-15 Sept	Spain	7	70,000+	2.5+ billion	11-15 Sept
15-17 Dec	France	3	10,000+	100+ million	15-17 Dec
29 Jun-04 Jul	Japan	2	1,000+	125+ million	29 Jun-04 Jul
26-28 Feb	California, USA	1	6,000+	175+ million	26-28 Feb
24-26 Oct	Italy	1	1,000+	590+ million	24-26 Oct
24-25 Mar	New Zealand	1	2,000+	15+ million	24-25 Mar
13-16 Mar	Canada	0	11,000+	240+ million	13-16 Mar

According to Table 2, It appears that flood damages are considerably greater in developing and rising nations in comparison to developed ones. For example, the death toll in Indonesia, Pakistan, and Bangladesh exceeded 100, yet in Spain, France, and Japan, it remained around 10. Nevertheless, the economic losses appear to be notably greater in wealthy nations compared to developing ones. The economic losses in the floods in Italy, which resulted in one fatality, exceeded $590 million. In contrast, the floods in Bangladesh, which claimed the lives of 210 individuals, resulted in financial losses of only $75 million.

Furthermore, as stated by (Bubeck & Thieken, 2018), floods can also lead to interruptions in several networks, including transportation, as was shown in Germany. The 2013 massive flood in Germany disrupted the functioning of numerous railways, with 75% of the routes being closed. This included a significant route connecting Berlin to places like Frankfurt and Cologne, which was also impacted. For instance, the flood caused significant harm to many high-speed railway tracks, resulting in the suspension of the route for a duration of 5 months. This closure necessitated the redirection of nearly 10,000 passenger trains and 3,000 freight trains onto alternative routes (Bubeck & Thieken, 2018). The severity of indirect impact on a country's economy can be measured by considering several factors. These factors include the total amount of indirect losses, the ability to recover from the lack of necessary resources, and the characteristics of the economy, such as whether it is a developing or industrialized economy (Zeng et al., 2019). The quantification and assessment of indirect economic repercussions are not given as much attention as direct losses; however, efforts are underway to create methods for measuring these implications. One example of a current assessment model for indirect impacts is the evaluation of health issues caused by high-standard infrastructures and hygiene levels (Bubeck & Thieken, 2018).

2.5. Global Best Practices to Enhance Flood Management

Various international organizations and efforts have been formed to mitigate natural disasters, including floods. The majority of global strategies acknowledge the significance of cooperative endeavors in mitigating and handling natural calamities (Bera, 2019; Etinay et al., 2018). One example of such global organizations is the International Decade for Natural Disaster Reduction (IDNDR), initiated by the United Nations in 1990. The objective of the decade is to alleviate natural disasters, specifically in underdeveloped nations, by coordinated international endeavors. The initiative aims to mitigate the loss of lives and property, economic disruptions, and poverty that are linked to natural catastrophes (Schemper, 2019). The decade serves several purposes in the areas of urban risk and planning, earthquake management, disaster risk management, governance, environmental and ecosystem preservation, floods, education, and school safety, among other domains (Imperiale & Vanclay, 2019). Ideally, the program operates through partnership. The program was developed based on the idea that effective natural disaster management necessitates sufficient resources and non-resource competencies, including skills, technology, and knowledge, which are often lacking in developing nations. Therefore, the cooperation of international allies, particularly the more advanced nations, presented a chance to enhance the ability of developing countries to handle natural disasters (Goldammer, 2017). The primary objective of the IDNDR was to prioritize the safeguarding and mitigation of natural calamities. The International Strategy for Disaster Reduction (ISDR) was implemented in 2000 to better improve the management of natural disasters. The primary objective was to improve the mitigation of natural disasters by integrating awareness, risk management, and risk assessment (Zentel and Glade, 2013; Chen et al., 2019). The program is a collaborative effort that includes government agencies, communities, and other interest groups, such as both for-profit and non-profit organizations (Zentel and Glade, 2013).

The Hyogo Framework for Action 2005-2015 (HFA) was a major achievement in enhancing the capacity of nations and communities to withstand and recover from disasters. The Hyogo framework was created during the World Conference on Disaster Reduction, held in Hyogo, Japan from January 18-22, 2005 (Enia, 2020). The meeting provided a rare chance to create systematic and strategic methods to reduce the vulnerability of governments and communities to disasters (UNISDR, 2011; Djalante et al., 2012; Sayers, 2017). Prior to the establishment of the HFA, the inaugural global conference on mitigating natural disasters - the Yokohama Strategy and Plan of Action for a Safer World - was formulated in 1994. The identification of current and distinct difficulties in disaster risk management, which formed the basis for the Hyogo framework, was made possible by reviewing the progress of the Yokohama strategy. This assessment drew upon several sources including IDNDR (1994), Tozier de la Poterie and Baudoin (2015), Mal et al. (2018), and Enia (2020). The difficulties encountered in implementing the Yokohama plan were linked to five primary domains (IDNDR, 1994).

- Governance: legal, organizational, and policy framework.
- Reduction of risks, monitoring and assessment and early warnings.
- Education and knowledge management.
- Reduction of the underlying factors.
- Preparedness for effective response and recovery.

After analyzing the difficulties described in the areas mentioned above, and reviewing the Yokohama plan, the following activities were determined to be of highest importance (IDNDR, 1994):

- Ensure that reduction of disaster risk is both a national, and local priority which are strongly founded on institutions;
- Early identification, assessment, and monitoring of disaster risks to enable early warning of potential disaster;
- Build a safety culture through the use of innovation, knowledge, and education in
- order to enhance resilience at all levels;
- Identify and reduce the disaster risks underlying factors;
- Strengthen the local and national government preparedness for disaster management.

The Sendai Framework for Disaster Risk Reduction 2015-2030 (SFFDRR) is an international disaster management initiative that was developed in 2015 during the Third United Nations World Conference in Sendai, Japan. The Sendai framework was formulated in a comparable fashion to the Hyogo framework (UNISDR, 2015). The Hyogo framework was created to cover the time span from 2005 to 2015. Subsequently, it was imperative to evaluate, derive lessons from it, and develop a new framework. The development of the SFFDRR was informed by a comprehensive analysis of the Hyogo framework, which highlighted difficulties and formulated improved solutions to strengthen disaster risk management (Saulnier et al., 2019; Wahlström, 2015). One important insight gained from the evaluation of the Hyogo framework is that despite the framework's existence, catastrophe risk and its consequences have continued to endure throughout the past decade. Between the years 2005 and 2015, a minimum of 700 thousand lives were lost due to disasters, and 1.4 million individuals were injured, according to the UNISDR in 2015. This suggests that the frameworks are insufficient in addressing the flood difficulties faced by humanity, and further measures are necessary to properly manage flooding. One important lesson that has been learned is that the rate at which people and assets are exposed to disasters has increased more rapidly than vulnerability (Maly & Suppasri, 2020). Therefore, it was imperative and pressing to formulate an additional strategy for catastrophe mitigation. The Sendai framework was established with a specific emphasis on the following key areas (UNISDR, 2015):

- Understanding more, the disaster risk.
- Strengthening disaster risk governance to manage disaster risk.

- Increase investment in disaster risk reduction for resilience.
- Enhancing disaster preparedness for effective response and to "Build Back Better" at post-disaster.

Within each of the priority areas, specific goals are designed to guide the enhancement of effective disaster management. Among the identified actions are to include the promotion of data collection and analysis, use and management to enhance better the stakeholders understanding of the disaster risks (Surianto et al., 2019; Mizutori, 2020). Under the priority area of strengthening disaster risk management, the main objective is to integrate the efforts and actions of disaster risk reduction in all sectors, and by all stakeholders. Regarding the priority area of investment, the major goal is to allocate adequate resources such as finances, administration, and necessary logistics to strengthen the implementation of the disaster risk management in terms of policies, plans, laws, and other necessary aspects. With respect to the priority area of preparedness to disasters to enhance effective response and develop better recovery mechanisms, the approach is to require involvement of the community to effectively implement it. More countries and state agencies across the globe are now interested in involving the community and obtaining feedback from it in consequence (Pearson and Pelling, 2015; Tozier de la Poterie and Baudoin, 2015; UNISDR, 2015; Wahlström, 2015; van Niekerk et al, 2020).

While the HFA implemented initiatives to promote resilience, the SFDRR focused on a more precise and technical definition of resilience to describe the developmental progress made after a disaster. It goes beyond the HFA by incorporating the aspirations of its members to encompass not just response measures for risk reduction, but also the implementation of effective restoration efforts, including reconstruction periods (Aitsi-Selmi et al., 2016). The SFDRR also addressed the significance of technology transfer in improving early warning systems (Deeming et al., 2019). In addition, the Sendai Framework for Disaster Risk Reduction (SFDRR) seeks to incorporate both disaster risk reduction (DRR) and the United Nations' Sustainable Development Goals (SDGs), so contributing to a broader and more inclusive development agenda (Etinay et al., 2018). Nevertheless, some detractors have deemed this structure to be inefficient in facilitating significant and crucial advancements. The primary objective of the SFDRR is to address the shortcomings of the previous framework by acknowledging the capabilities of communities and the pressing need to incorporate scientific and local knowledge. However, there was a lack of a clear strategy to involve communities in the decision-making process (Pearson and Pelling, 2015). In addition to the fact that the SFDRR aims are not legally enforceable, it is evident that the intergovernmental political process has struggled to keep up with advancements in both practical implementation and scientific knowledge. Consequently, engaging in individual discussions impedes the progress towards achieving sustainability (Etinay et al., 2018; Wang et al., 2023). The Sendai framework emphasizes the significance of collaboration across all stakeholders and levels of government in the context of the present study. Nevertheless, the framework presents the challenge of heightened funding for several aspects of flood risk management, such as planning, legislation, and associated policies. The Hyogo and Sendai frameworks also advocate for the utilization of more information and data in flood management.

At the local levels (Maly & Suppasri, 2020). The two frameworks are the most important international strategies. The effective flood management has been explained through the international settings and history. This begins from the international top-down government approach to government driven top-down approach and eventually to community-based bottom-up approach as illustrated in Figure 2.5.1.

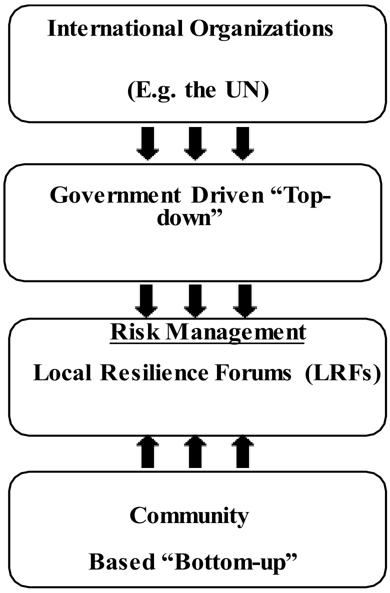

Figure 2.5.1: *Hazard risk management approach (Maly & Suppasri, 2020)*

2.6. Flood Vulnerability in Pakistan

Pakistan is ranked 18th out of 191 nations in terms of catastrophe risk levels, according to the 2019 Inform Risk Index, indicating that it faces some of the highest levels of danger in the world. The primary factor contributing to this danger is the country's vulnerability to earthquakes and the potential for internal conflicts. Nevertheless, Pakistan is highly susceptible to many types of flooding, such as riverine, flash, and coastal floods. It also faces a certain level of risk from tropical storms and their related dangers, as well as drought. Pakistan's social fragility contributes significantly to its disaster risk. Pakistan's vulnerability ranking, which is 37 out of 191, is mostly influenced by its elevated levels of multidimensional poverty. Pakistan demonstrates a somewhat superior ability to cope. Pakistan is prone to natural disasters, such as floods, which affect millions of people every year. Evidence has shown that the severity of floods is increasing and is likely to further rise in the future due to climate change-induced alterations in monsoon precipitation patterns in the country. In light of Pakistan's susceptibility to flooding, it is imperative to evaluate the susceptibility to floods in order to effectively plan for and alleviate their consequences. Pakistan is located in an area that is prone to both natural and human-caused disasters, such as floods ((Abbass et al., 2022; Ali et al., 2022; Khan et al., 2021). In the past few decades, a total of 124 districts in the country have been affected by various types of natural disasters, resulting in a collective impact on over 33 million individuals. The lowlands of the country are a crucial component of the Indus River system, which is prone to frequent flooding and has already experienced the effects of flooding. In 2010, the country had a severe flood as a result of heavy and protracted monsoon rains. This led to one-fifth of the land being flooded with water, as documented by (A. A. Shah et al., 2020; S. Ullah et al., 2018; W. Ullah et al., 2021). The repeated occurrences of floods suggest that the community, local government, and associated institutions lack adequate preparation and resources to effectively manage the issue. Therefore, it is necessary to introduce reforms to guarantee appropriate measures are done to prevent such floods from happening again (Ross and Cross,2010). Khyber Pakhtunkhwa, a significant province of Pakistan, has had multiple devastating floods in recent years, including in 2007, 2008, 2010, and 2012 (A. A. Shah et al., 2020). The province has a crucial role as a pathway for riverine floods because of its rivers, such as the River Swat and River Kabul, and their tributaries (Khan et al., 2021). The district of Charsadda in Pakistan is highly susceptible to flooding due to the Swat and Kabul Rivers and their tributaries. This leads to considerable loss of life, damage to property and crops, disruption of daily activities, and environmental deterioration (Chitrali, 2010). In 2010, the Munda Headwork, a British-built structure dating back to 1920, suffered significant damage as a result of flooding. This flooding had a widespread impact on the channel system that provided water to a large area of agricultural land in Charsadda ((Saghafian et al., 2008). The floods in 2010 had significant implications for the villages and population living on the eastern side of Munda Headwork and the lower channel system that starts from the Swat River. This incident resulted in a significant number of deaths, with hundreds of fatalities, and caused a large section of the impacted people to be displaced. The residents residing in close proximity to the floodplain experienced extensive devastation, compelling the majority of survivors to relocate to adjacent secure regions and seek shelter in government institutions and private establishments (Rahman et al., 2019). Figure 2.6.1 and Figure 2.6.2 illustrate the mean yearly recurrence interval and statistical data on natural disasters from 1980 to 2020.

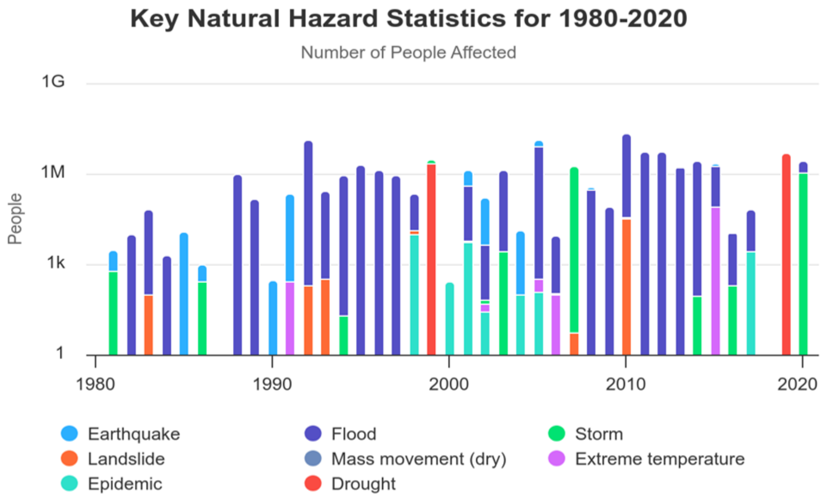

Figure 2.6.1: *Key Natural Hazards Statistics 1980-2020 (Rahman et al., 2019)*

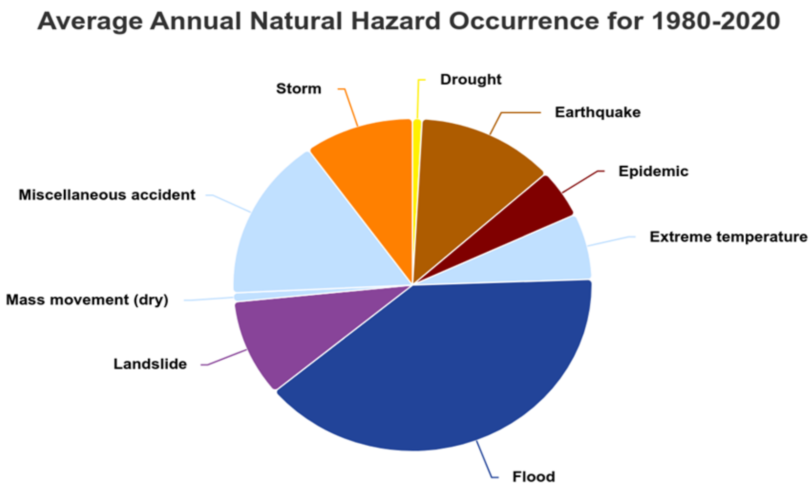

Figure 2.6.2: *Annual Average Natural Hazard Occurrence for 1980-2020 (Rahman et al., 2019)*

2.6.1. History of Floods in Pakistan

Floods accounted for about 30% of natural hazards in the previous century, resulting in significant destruction, loss of human life, and damage to valuable assets. Pakistan is ranked 8th in terms of countries most impacted by climate change and 7th in terms of vulnerability to climate change, according to the global climate risk index (GCRI) by German Watch (A. A. Shah et al., 2020). Pakistan saw an average of one flood every three years from 1950 to 2011, along with around 21 severe floods. The floods resulted in the loss of 8887 human lives and had an indirect economic cost of $19 billion (Ali et al., 2022). Prior to the monsoon floods in 2022, Pakistan saw its most severe flooding ever recorded in 2010. The 2010 mega floods resulted in the unfortunate demise of 1985 individuals, a substantial financial loss of $9.7 billion, and had an impact on 0.2 billion people in the nation. Nevertheless, the precise extent of the economic losses that cannot be physically measured is still to be determined (S. M. H. Shah et al., 2020). Pakistan saw extensive flooding during the monsoon season in 2022. The United Nations (2022) reported that the monsoon floods in 2022 resulted in the deaths of at least 1033 individuals. Additionally, the floods affected 33 million people, displacing 5.4 million individuals. Furthermore, 72 districts were officially declared as 'calamity stricken.' The floods also caused the destruction of 2 million acres of crops and orchards, as well as 2 million residences. During the catastrophic incident of 2010, a total of 392,786 houses were rendered damaged, while 728,192 houses were completely destroyed. The districts of Muzaffargarh and Rajanpur in the Punjab, Nowshera and D.I.Khan in KPK, and Jaffar Abad, Jacobabad, Shikarpur, and Thatta in Sindh had the most significant damage.

Table 3: *Flood Damages and Reconstruction Costs in Billions (National Flood Reconstruction Plan 2010)*

Province/Area	Damages	Reconstruction Cost
AJK	7	13
Balochistan	53	27
FATA	6	8
Federal	93	96
Gilgit Bultistan	4	7
Khyber Pakhtunkhwa	100	106

Punjab	219	93
Sindh	373	228
Total	**855**	**578**

Table 4: Major Flood Events Wetness in Pakistan (S. M. H. Shah et al., 2020)

S. No	Year	Direct Losses (US$ million) 1US$~ PKR 86	Lives Lost (No)	Affected Villages (No)	Flooded area (Sq-Km)
1.	1950	488	2,190	10,000	17,920
2.	1955	378	697	6,945	20,480
3.	1956	318	160	11,609	74,406
4.	1957	301	83	4,498	16,003
5.	1959	234	88	3,902	10,424
6.	1973	5,134	474	9,719	41,472
7.	1975	684	126	8,628	34,391
8.	1976	3,485	425	18,390	81,920
9.	1977	338	848	2,185	4,657
10.	1978	2,227	393	9,199	30,597
11.	1981	299	82	2,071	4,191
12.	1983	135	39	643	1,882
13.	1984	75	42	251	1,093
14.	1988	858	508	100	6,144
15.	1992	3,010	1,008	13,208	38,758
16.	1994	843	431	1,622	5,568
17.	1995	376	591	6,852	16,686
18.	2010	10,000 1S$-PKR 86	1,985	17,553	160,000
19.	2011	3730	516	38,700	27,581

		1US$-PKR94			
20.	2012	2640 1US$-PKR 95	571	14,159	4,746
21.	2013	2000 1US$-PKR 98	333	8,297	4,483
22.	2014	440 1US$-PKR 101	367	4,065	9,779
23.	2015	170 1US$-PKR 105	238	4,634	2,877
24.	2016	6 1US$-PKR 104	153	43	-
25.	2017	-	172	-	-
26.	2018	-	88	-	-
27.	2019	-	235	-	-
28.	2020	-	409	-	-
Total		**38,169**	**13,262**	**197,273**	**616,558**

2.6.2. Causes of Floods in Pakistan

Heavy concentrated rainfall in the river catchments, often combined with snowmelt flows, is the primary source of floods in Pakistan, particularly during the monsoon season. Periodically, Monsoon currents that originate in the Bay of Bengal (India) and the resulting depressions frequently lead to intense rainfall in the Himalayan foothills. These areas are also affected by weather systems from the Arabian Sea (Seasonal Low) and the Mediterranean Sea (Westerly Wave), which further contribute to destructive floods in one or more of the main rivers of the Indus System. However, in certain instances, extremely elevated floods have sporadically occurred as a result of the creation of temporary natural barriers produced by landslides or glacial shifts, followed by their subsequent collapse. Almost all river discharges experience significant seasonal changes, which worsen the condition and shape of the river. Flood losses are mostly caused by major rivers through the inundation of areas along their banks, the destruction of irrigation and communication infrastructure along or across the rivers, and the erosion of land along the riverbanks. In the upper region of the Indus Basin System, floodwater that overflows from the riverbanks typically flows back into the river. However, in the lower section of the Indus River, where the river flows at a greater altitude than the surrounding areas, any overflow does not flow back into the river. This behavior significantly prolongs the duration of flooding, leading to even more extensive destruction. Despite the implementation of flood protection measures such as embankments along most of the Sindh Province and in many upper places, there is still a risk of breaches in the bunds. These breaches frequently result in more significant harm than would have happened if the bunds were not present, due to their unforeseen occurrence and the increased utilization of land after flood protection measures are implemented. The insufficient discharge capacity of certain crucial buildings (like as barrages and rail or road bridges) on the Indus, Chenab, and Ravi rivers is another significant factor. During periods of extremely high floods, there is an increase in water level on the upstream side, which might lead to breaches in the flood embankments (Ishaque, Tanveer, & Mukhtar, 2022). Occasionally, it is necessary to intentionally breach the flood embankments at specific points in order to protect the main barrage structures and other important communities and installations nearby. The expansion of village settlements in locations along rivers has also heightened the extent of flood-related destruction and casualties to both humans and livestock. Due to the absence of a comprehensive legal framework for settlement in riverine areas, many impoverished individuals have built their homes near the exposed riverbanks, making them susceptible to catastrophic flooding. Certain individuals are capitalizing on these regions for commercial purposes by expanding agriculture and establishing cattle Ghats/dairies (Shahid & Ashraf, 2021). These operations are beyond the safe boundaries of riverine areas in order to gain additional economic advantages. However, they are actually posing a significant risk of severe and uncontrolled flooding. The resulting losses from these floods could be hundreds of times greater than the small-scale economic profits gained. The river catchments and flood plains will be designated as restricted areas for the riverine communities, particularly during the flood season. Over the past few years, the susceptibility of major urban areas to floods has escalated. Metropolitan areas such as Karachi, Lahore, and Rawalpindi have encountered flooding as a result of the drainage system's inability to handle intense rainfall.

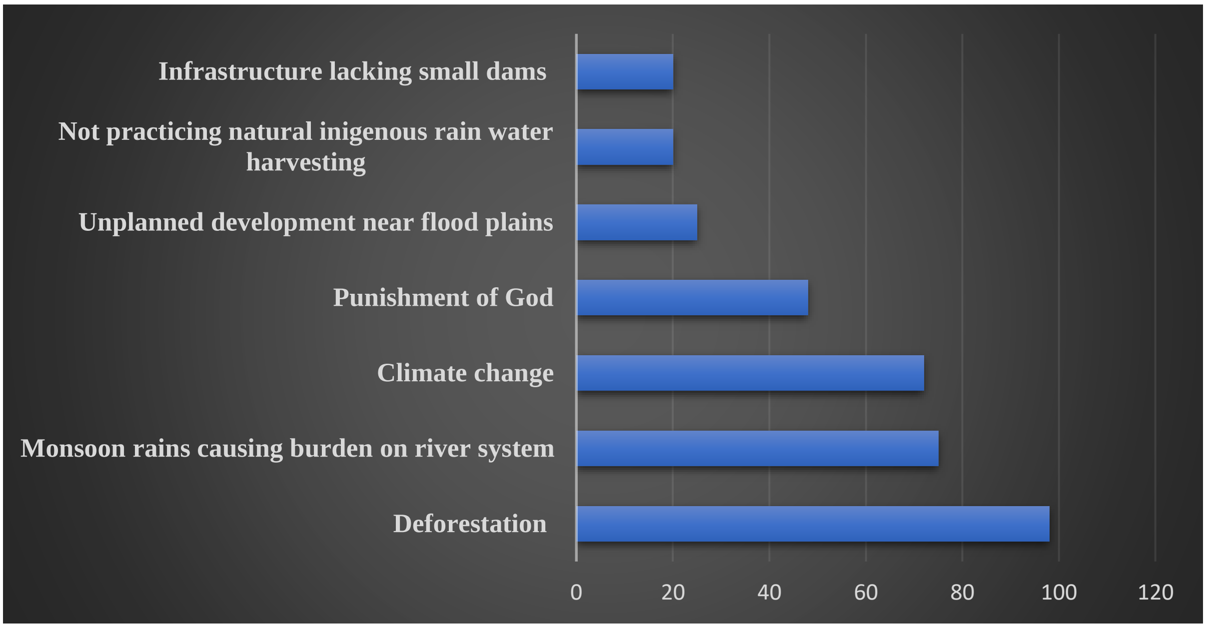

Figure 2.6.3: *Causes of floods in Pakistan (Ishaque, Tanveer, & Mukhtar, 2022)*

2.6.3. Flood Management in Pakistan

The flood prevention plan is a relatively intricate challenge in Pakistan. The intricacy of the issue varies in each of the four provinces due to their distinct physiographic, climatic, topographical, and socioeconomic situations (Georgakakos et al., 2012). Significant floods occurred in 1950, 1956, and 1957 shortly after gaining independence. Nevertheless, due to limited financial resources and administrative frameworks, a comprehensive flood control initiative was not established on a nationwide scale. Regional governments had sole responsibility for the protection and control of flooding until 1976. The situation improved significantly following the devastating floods in 1973, which resulted in the loss of 474 lives and inflicted damage amounting to 160 billion Pakistani Rupees (Tariq & Van de Giesen, 2012).

Figure 2.6.4: *Overview of Flood Management (Georgakakos et al., 2012)*

2.6.4. Evolution of Flood Management in Pakistan

Pakistan had devastating floods in 1973, prompting the creation of the Federal Flood Commission (FFC) in 1977. The commission operated inside the Ministry of Water and Power and was created to carry out countrywide flood management, with a specific focus on the Indus River Basin. The primary responsibilities of the FFC encompass the formulation of (Pictures of 2010-Floods, n.d.)national strategies for flood management, endorsement of flood management plans devised by local governments and federal entities, assessment of flood-related damages to public infrastructure, analysis of repair and rehabilitation proposals, improvement of flood forecasting and alert systems, and provision of guidelines for the management of flood protection reservoirs (By Syed Sajidin Hussain, n.d.) The initial iteration of the National Flood Protection Plan (NFPP-I) was formulated subsequent to the establishment of the FFC, with a budgetary schedule intended for implementation across the span of the 1978-1988 period. In 1982, a Federal Coordination Cell, which has now been renamed as FID Cell, was established to efficiently manage the operations of the Provincial Irrigation Departments, particularly in the drainage zone. The Dam Protection Council was founded in 1987 to assess existing dams managed by DSO WAPDA and to evaluate plans for additional dams, as stated in the GoP Annual Flood Report of 2009. Pakistan's flood control efforts largely involve the construction of flood-protection embankments, spurs, studs, and the implementation of advanced flood-prediction systems. Provincial governments have implemented multiple flood-protection measures to tackle specific flood issues at the local level (Berndtsson et al., 2019). According to (Ali et al., 2022), flood risk mitigation in Pakistan was predominantly managed by federal and provincial authorities. However, it is necessary to reassess these approaches and develop creative methods and tactics to effectively mitigate the hazard. Figure 8 illustrates the flood management institutions and their corresponding tasks.

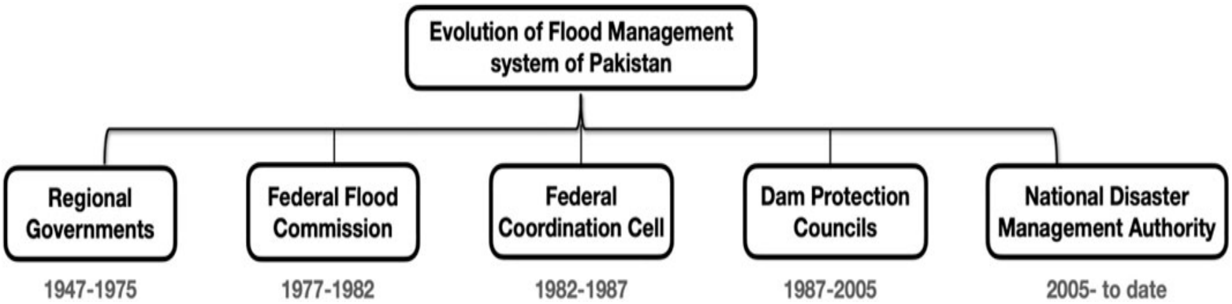

Figure 2.6.5: *Flood Management System of Pakistan (Ali et al., 2022)*

2.6.5. The Challenge of Flood Management

Both population increase and economic growth significantly impact the natural resources of a system. The combination of growing population density and intensified economic development in floodplains, including the construction of buildings and infrastructure, exacerbates the likelihood of flooding. Floodplains offer highly favorable and straightforward alternatives for livelihood in numerous instances. In developing nations that rely heavily on agriculture, ensuring access to food is directly linked to ensuring the stability and sustainability of people's livelihoods. Floodplains play a significant role in the agricultural production that supplies nourishment for the populations of these nations. Although virtual water trade could potentially mitigate the problem of food security by reducing reliance on flood-prone and water shortage regions, it would not solve the issue of livelihood security. The rivalry for scarce land resources might pose a threat to the more vulnerable segments of the population, who predominantly reside in the floodplains. It is necessary to evaluate the impact of resettlement programs and other floodplain policy measures on the livelihood chances of vulnerable communities. Swift urbanization Population growth in rural areas typically hinders the improvement of living standards beyond mere subsistence. Agricultural livelihoods rely on unpredictable environmental conditions, and during periods of drought, flood, or crop failure, life becomes exceedingly challenging. Given these circumstances, individuals migrate from rural areas to urban centers in pursuit of economic prospects and improved availability of essential amenities. Climate change is expected to speed up the movement of people into cities by changing the ways people make a living through fishing and farming, and by making natural disasters happen more often and have stronger impacts. The urban share of the worldwide population increased from 13 percent in 1900 to 49 percent. Virtual water, often referred to as embedded water, embodied water, or concealed water, pertains to the water utilized in the manufacturing process of a commodity or service inside the framework of trade. In the year 2005. According to the United Nations Department of Economic and Social Affairs (2007), it is expected that this percentage would increase to 57% by 2025 and over 70% by 2050. The majority of this process of urbanization will occur in emerging nations, where the expansion is predominantly spontaneous and natural, principally happening in Asia and Africa, and to a smaller degree in Latin America and the Caribbean. Urbanization induces alterations in the hydrological response of watersheds, impacting landforms, water quality, and habitat. The rise in population and migration towards unplanned urban settlements on floodplains in developing countries heightens the susceptibility of the most impoverished elements of society to floods. The significant concentration of urban expansion in coastal areas poses a significant risk of heightened susceptibility to floods for these communities, mostly due to the anticipated rise in river and coastal flooding caused by climate change. These segments of society also experience a dearth of health and sanitation amenities, making them more susceptible to disasters and their aftermath. Flood management policies must take into account the requirements of these societies.

2.6.6. Integrated Approach in Flood Management

Integrated Flood control (IFM) is a comprehensive method based on the principles of Integrated Water Resources Management (IWRM). It emphasizes the connection between socio-economic development, environmental sustainability, and flood-risk control. IFM Plans serve as a basis for making decisions connected to floods, since they outline the necessary elements of sectoral development that need to be incorporated in order to effectively manage floods in a sustainable manner. This tool offers an overview of the Integrated Flood Management (IFM) strategy and examines essential principles and procedures for successful IFM planning(Munawar et al., 2022). Previously, floods were seen as a natural occurrence related to water; only physical and non-physical actions were taken to address this event. However, now the primary concerns are the welfare of the people living in areas prone to flooding, their economic development, and the urgent need to reduce poverty in these affected regions. Sufficient effort is necessary to tackle these challenges from both a national and regional standpoint. The regional perspective is crucial because actions performed in one nation can have either beneficial or negative impacts on the occurrence of floods in other countries within the region, especially those located downstream. In order to fully utilize the knowledge acquired from flood management efforts in neighboring countries, it is crucial to engage in the exchange of ideas and experiences, as well as the sharing of data and information. By collaborating and fostering an open and trusting environment, we can collectively develop effective approaches and methods to tackle important flood management challenges at both national and regional levels. The incidence of flood-related disasters has increased by 134% since 2000, in comparison to the two preceding decades (WMO, 2021). The lack of adequate focus on flood risk management has led to a significant rise in the number of individuals impacted and the financial losses associated with floods (Suriya & Mudgal, 2012)). According to the World Bank, floods have affected almost 1.65 billion individuals between 2000 and 2019 (World Bank, 2021). According to the GWP/OECD Task Force on Water Security and Sustainable Growth, the annual cost of flood losses to urban properties is projected to be around US$120 billion (Islam & Sado, 2000)).

Historically, flood control and protection measures have mostly focused on engineering solutions, neglecting the social, cultural, and environmental impacts of these measures, as well as the long-term economic viability. There is an increasing acknowledgment that non-structural components can also have a significant impact in mitigating the socio-economic consequences of flooding. Recently, there has been a noticeable change in the way we approach flood control, moving away from the traditional focus on constructing dikes and dams. The Integrated Flood Risk Management approach is a solution to the demand for a more efficient, comprehensive, and future-oriented strategy for flood management (Tariq & Van de Giesen, 2012).

Figure 2.6.6: *7 Integrated Flood Risk Management (Suriya & Mudgal, 2012)*

2.6.7. Key Flood Management Institute in Pakistan

Pakistan's flood management structure extends from the national to the local level. At the national level,

Federal Flood Commission (FFC) coordinates flood control and infrastructure projects, while the **National Disaster Management Authority (NDMA)** oversees disaster preparedness and response. **Pakistan Meteorological Department (PMD)** provides essential weather forecasts and flood warnings.

Provincial Disaster Management Authorities (PDMAs) implement flood management strategies and coordinate emergency responses.

District Disaster Management Authorities (DDMAs) play a crucial role in executing local flood management plans, coordinating relief efforts, and ensuring timely community response during flood events. These institutions collectively work to mitigate flood risks and manage disaster responses effectively throughout the country.

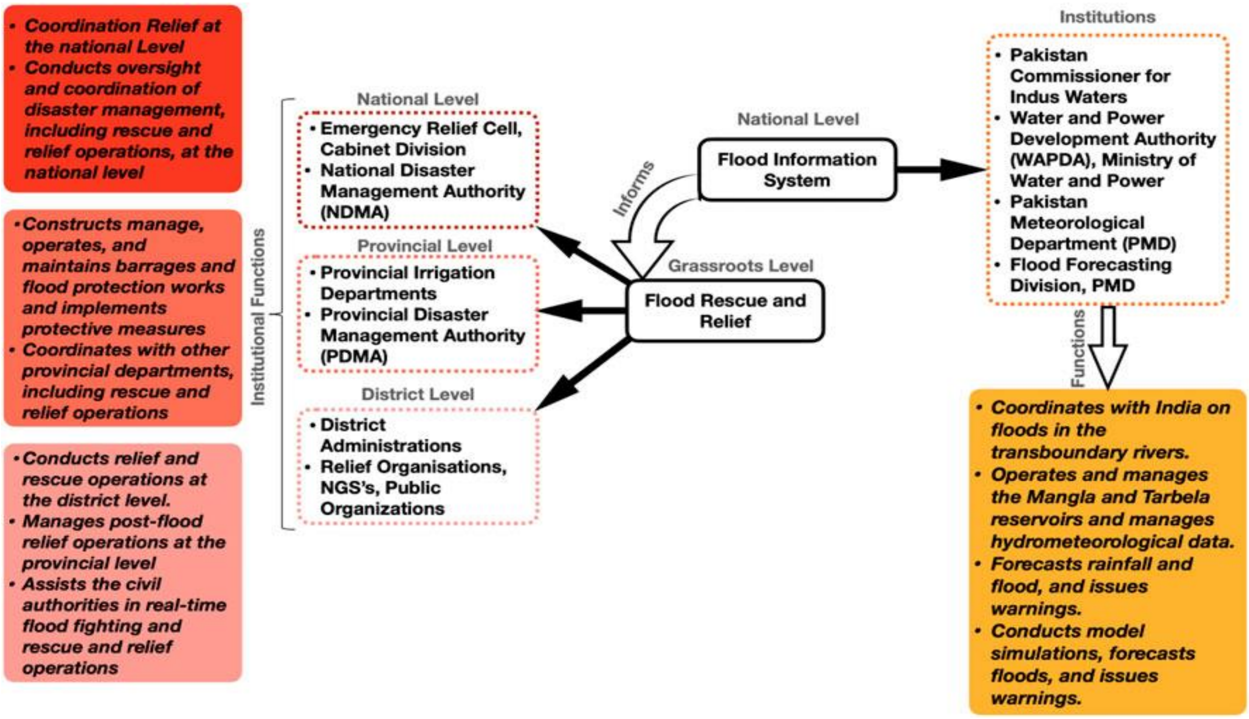

Figure 2.6.7: *Flood management Institutes and their Responsibilities*

2.6.8. Historical Development of Flood Forecasting Strategies

The advancement of flood forecasting has evolved from basic observational methods to complex predictive models. The introduction of hydrological research brought about systematic approaches, such as deterministic models that rely on the relationship between rainfall and runoff, which improved the accuracy of forecasts. This framework differentiates between the conventional empirical and fundamental modeling methodologies and the more sophisticated technical solutions that incorporate real-time data, intricate modeling, and thorough risk management.

2.7. Traditional Forecasting Strategies

Initially, flood forecasting depended on conventional techniques, namely empirical observations and fundamental hydrological models. Ancient civilizations relied on natural signs, such as fluctuations in river levels and weather patterns, to anticipate and forecast probable occurrences of flooding(Rajagopalan et al., 2024). Although these approaches were easy to understand, they had limitations in terms of accuracy and range, frequently offering inadequate advance notice. As hydrological science advanced, more organized methods arose, such as the utilization of deterministic models that rely on historical rainfall and runoff data. These models included basic computations of river discharge, providing a basic capability to forecast floods but still lacked accuracy and immediate reactivity.

2.8. Technical Forecasting Strategies

With the advancement of technology, flood forecasting systems have undergone substantial evolution, adopting digital solutions that have improved both accuracy and timeliness. In the mid-20th century, radar technology was introduced, enabling the real-time tracking of storm systems and thereby enhancing the amount of time available for issuing warnings. The incorporation of meteorological data into hydrological models has become a common practice, thanks to the progress in computer technology that has allowed for more intricate simulations(Vaughan et al., 2019). The utilization of remote sensing technologies, such as satellite images, and Geographic Information Systems (GIS) facilitated the acquisition of extensive spatial data for the purpose of monitoring and mapping flood-prone areas on a wide scale. The advancements were further improved by the creation of probabilistic forecasting models, which provided a variety of potential results and aided decision-making in situations with unknown outcomes(Keogh et al., 2011). The advent of the Internet and telecommunications technology brought about a significant transformation in the way information is spread, allowing for swift distribution of flood warnings via early warning systems. Contemporary forecasting methods now integrate climate change estimates and employ high-resolution data and advanced modeling approaches. This enables the provision of precise and timely flood predictions, which are crucial for effective risk management.

2.9. Modern Technologies in Flood Forecasting

Modern flood forecasting systems employ advanced modeling, data collection, and analytical methods to more effectively predict and manage flood events. Through the implementation of innovative flood control technology, significant progress has been made in mitigating the impact of floods in vulnerable areas(Wingfield et al., 2019). These technologies include advanced forecasting systems that utilize machine learning algorithms and satellite data to improve the accuracy of rainfall and river level predictions. In addition, smart water management systems also offer the capability to monitor and control water flow in real-time. This feature allows for optimal utilization of infrastructure such as levees, dams, and drainage systems. Collectively, these technologies not only help avert floods but also support the practice of sustainable water resource management(S. Ullah et al., 2018).

2.9.1. Remote Sensing and Satellite Imagery

Remote sensing and satellite photography play a crucial role in contemporary flood forecasting by offering extensive and up-to-date information on atmospheric and terrestrial variables. Satellites outfitted with diverse sensors have the capability to globally monitor rainfall patterns, snow cover, river levels, and soil moisture(Noy et al., 2021). This method facilitates the timely identification of weather systems that have the potential to cause flooding, providing a comprehensive perspective that is extremely helpful for predicting floods on a wide scale. The acquired data can be utilized to create maps of flood extents, evaluate the extent of damage in post-flood situations, and enhance the calibration of hydrological models. This makes it a crucial tool for assessing flood risks in both the short-term and long-term.

2.9.2. Geographic Information Systems (GIS)

Geographic Information Systems (GIS) combine and examine spatial data to generate intricate maps and visual representations of areas that are susceptible to flooding. GIS utilizes data integration of topography, land use, infrastructure, and hydrological factors to pinpoint locations susceptible to floods under different circumstances(Miao, 2019). This technology is essential for urban planning and disaster preparedness because it enables the simulation of flood occurrences and the assessment of potential effects on communities and infrastructure. GIS is essential in disaster response as it offers up-to-date information and visual aids that help decision-makers coordinate evacuations and allocate resources efficiently.

2.9.3. Hydrological and Meteorological Models

Complex hydrological and meteorological models are utilized to replicate the intricate processes of the water cycle and atmospheric conditions. These models are employed to predict the likelihood and intensity of floods(Gilissen et al., 2016). These models employ data assimilation techniques to integrate real-time observations, hence improving the precision of predictions. They have the capability to replicate intricate relationships among precipitation, surface runoff, river discharge, and groundwater, thereby offering precise predictions of both riverine and flash floods. These models play a crucial role in providing information to flood warning systems and assisting authorities in planning appropriate actions by accurately predicting the dates and levels at which floods would reach their highest point. In addition, they assist in the development of long-term climate adaptation strategies by evaluating the possible effects of climate change on the frequency and intensity of floods (Adger et al., 2018).

2.9.4. Machine Learning and Artificial Intelligence

The use of machine learning and artificial intelligence (AI) has fundamentally transformed flood forecasting by facilitating the examination of extensive and intricate datasets. These tools have the capability to detect patterns and correlations in past flood data, weather predictions, and environmental factors that may not be evident using conventional methods. AI models can enhance the precision of flood forecasts by iteratively assimilating fresh data, thereby honing their algorithms progressively(Demeritt & Nobert, 2014). They are especially valuable for predicting floods in real-time, as they can quickly process and evaluate incoming data, offering timely insights. AI's prognostic skills extend beyond immediate predictions, also assisting in long-term flood risk management by simulating the impacts of evolving land use and climate conditions.

2.10. Limitations and Challenges in Flood Management and Forecasting

The integration of current technologies with old approaches presents numerous obstacles and constraints in flood management and forecasting. A significant constraint is the inconsistency and caliber of the data. Obtaining reliable and complete hydroclimatic data in real-time is challenging, particularly in developing locations, yet it is crucial for effective flood forecasting. Several flood early warning systems (FEWSs) depend on conventional data collection methods, such as ground stations, which frequently suffer from limited spatial coverage and antiquated technology. This leads to a lack of comprehensive understanding of risks and hampers the capacity to make precise predictions about flood occurrences (Fernández-Montblanc et al., 2019). In addition, there is sometimes a dearth of technical skills needed to operate sophisticated forecasting models. Numerous forecasting centers have challenges due to insufficient staffing and a scarcity of proficient professionals capable of effectively handling intricate data integration and analysis. The lack of technical capacity is impeding the progress and implementation of high-resolution predictive models, which are essential for precise forecasting and timely distribution of warnings. The inadequate allocation of funds towards contemporary equipment and infrastructure, coupled with a scarcity of skilled professionals, intensifies these difficulties, especially in developing nations with limited resources (Frigerio & De Amicis, 2016).

Additionally, the dissemination and communication of flood warnings remain problematic. Even when accurate forecasts are made, effectively communicating these warnings to the public, especially to vulnerable and remote communities, poses significant challenges. Barriers such as limited access to communication technologies, inadequate public education on flood risks, and socio-economic factors like illiteracy and poverty, impede the effective delivery and reception of critical information. These issues can lead to delayed responses and increased vulnerability to flood impacts (Paltan et al., 2017).

Finally, the intricacy and unpredictability of flood behavior provide intrinsic difficulties. Flood models, whether they are hydrological or hydraulic, need to deal with the unpredictable characteristics of weather systems and the varied geographical features of the impacted regions. The intricate nature of this situation frequently leads to a certain level of ambiguity in predictions, which can impact the process of making decisions and responding to emergencies. Continuous research and technical improvement in flood modeling are essential to resolve uncertainties and enhance the overall resilience of flood control systems (Takagi et al., 2016). The significance of improving data quality, technological skill, and communication infrastructure in flood control is emphasized by these restrictions. It is crucial to tackle these difficulties to create better and more thorough solutions for reducing the effects of floods.

2.11. Summary

The literature review examines the rising occurrence and severity of floods on a global scale, highlighting its correlation with climate change and urbanization. It emphasizes the impact of increasing global temperatures on the intensity of rainfall and flooding, which has consequences for both wealthy and developing nations. The paper emphasizes the significance of contemporary flood management methodologies, such as the utilization of cutting-edge technologies like remote sensing and Geographic Information Systems (GIS), to accurately forecast and control these natural calamities. Furthermore, it emphasizes the crucial requirement for strong emergency preparedness and response measures, as exemplified by the significant floods resulting from Hurricane Harvey in Houston, Texas, in 2017.

The literature analysis highlights that Pakistan is particularly vulnerable to multiple forms of flooding, such as riverine, flash, and coastal floods. In recent decades, Pakistan has had several catastrophic flood incidents, including the disastrous floods in 2010 that caused more than 1,985 fatalities and impacted almost 20 million individuals. These catastrophes emphasize the severe human and economic costs, such as loss of life, displacement of populations, and extensive damage to infrastructure and crops. Pakistan's susceptibility to floods is worsened by its socio-economic circumstances, such as elevated poverty levels and insufficient infrastructure, which impede the ability to respond to and recover from disasters effectively. The analysis highlights the pressing requirement for enhanced flood management methods throughout the nation, incorporating modern forecasting technologies and adaptive strategies to reduce the effects of future flood disasters.

CHAPTER 3: METHODOLOGY

3.1. Introduction

This chapter outlines the research methodology employed to investigate the significance of modern technology-based flood forecasting and anticipation in Pakistan, with a particular focus on the National Emergency Operation Centre (NEOC). The methodology is designed to provide a comprehensive and rigorous approach to exploring existing flood management policies, reviewing innovative flood management approaches globally, and assessing the role of the NEOC in flood hazard assessment in Pakistan.

The chapter is divided into several sections, each addressing a specific aspect of the research methodology. The first section provides an overview of the research design, including the rationale for choosing a mixed-methods approach. The second section details the data collection methods used, including literature review, policy analysis, case study analysis, and both qualitative and quantitative data gathering techniques. The third section outlines the data analysis techniques employed, including qualitative and quantitative methods. The fourth section addresses ethical considerations, ensuring that the research was conducted in a responsible and ethical manner. Finally, the chapter concludes by acknowledging the limitations of the study and discussing potential areas for future research.

3.2. Research Deign

A comprehensive literature review was conducted to identify the current challenges and gaps in flood management strategies in Pakistan. This involved searching through academic journals, government reports, and other relevant sources to identify existing studies and research findings related to flood management in Pakistan. Once the challenges were identified, a second literature review was conducted to explore best practices from around the world for addressing these challenges. This involved identifying successful case studies, innovative approaches, and technological solutions that have been implemented in other countries. Through the literature review, the NEOC was identified as a modern tool being used in flood management worldwide. This led to the decision to conduct a case study of the NEOC in Pakistan to assess its capabilities and effectiveness.

The case study focused on the NEOC's capabilities in projections, early warnings, and forecasting. This involved conducting in-depth interviews with key stakeholders at the NEOC, analyzing relevant documents, and observing the NEOC's operations during flood events. The case study aimed to assess the effectiveness of the NEOC's presence in Pakistan. This involved evaluating the accuracy of its projections, the timeliness of its early warnings, and the impact of its forecasting on flood management outcomes.

While no formal statistical analysis was conducted, the research relied on qualitative data analysis techniques to analyze the information gathered from the literature review, case study, and interviews. This included thematic analysis, content analysis, and narrative analysis to identify patterns, themes, and insights from the data.

The qualitative data analysis allowed for a detailed exploration of the NEOC's operations, decision-making processes, and the effectiveness of its flood management strategies. It provided valuable insights into the strengths, weaknesses, and challenges faced by the NEOC and highlighted the potential of modern technology-based approaches to improve flood forecasting and anticipation in Pakistan.

3.3. Data Collection

This research employed a mixed-methods approach, combining both qualitative and quantitative data collection techniques. The specific methods used were:

3.3.1. Literature Review

A comprehensive literature search was conducted using databases such as Google Scholar, PubMed, Scopus, and institutional libraries to identify relevant academic journals, government reports, policy documents, and other publications pertaining to flood management, disaster risk reduction, and the use of technology in disaster response in Pakistan. Sources were carefully selected based on their relevance to the specific research objectives, ensuring that the literature review covered a wide range of perspectives and methodologies. Priority was given to recent publications to ensure the inclusion of the latest research and developments, while older studies were also considered if they provided valuable historical context or insights into long-standing challenges. Once identified, the selected sources were systematically analyzed to extract relevant information. This involved identifying key themes, trends, and gaps in existing knowledge related to flood management, disaster risk reduction, and the use of technology in Pakistan. The extracted data was carefully examined to identify patterns, contradictions, and areas for further investigation. Additionally, the literature review aimed to identify innovative technologies and best practices from around the world that could be applied to the Pakistani context to enhance flood management efforts.

3.3.2. Policy Analysis

A comprehensive search was conducted to identify and collect relevant policy documents, strategies, and guidelines from national and provincial government sources, including the National Disaster Management Authority (NDMA) and Provincial Disaster Management Authorities (PDMAs). This search included a review of official websites, government gazettes, and other relevant repositories, such as academic databases and think tank publications, to ensure that all pertinent documents were identified. Once collected, a detailed content analysis was conducted to identify policy objectives, implementation strategies, and gaps or challenges within the existing framework. The analysis involved a systematic examination of the content of the policy documents, including their stated goals, objectives, and strategies, as well as their alignment with international best practices in flood management. Additionally, the analysis aimed to assess the effectiveness of the policies in addressing the specific challenges and vulnerabilities faced by Pakistan in terms of flood management, including the country's geographical location, climate patterns, and socio-economic conditions. The analysis also considered the impact of these policies on flood resilience, preparedness, and response efforts at the national, provincial, and local levels.

3.3.3. Case Study Analysis

A comprehensive analysis of relevant documents, including advisories, projections, situational reports, media reports, Pakistan Meteorological Department (PMD) rainfall data, Flood Forecasting Center (FFC) annual reports, and other pertinent sources, was conducted to gain a deep understanding of the National Emergency Operation Centre (NEOC)'s role, effectiveness, and impact in flood management and disaster response in Pakistan. This analysis aimed to assess the NEOC's ability to coordinate flood response efforts, disseminate information accurately and timely, and provide effective early warnings. By examining a wide range of documents, the research sought to identify the NEOC's strengths, weaknesses, and areas for improvement, as well as its contribution to mitigating the impacts of floods on communities, infrastructure, and the economy. Additionally, the analysis aimed to evaluate the NEOC's alignment with international best practices in flood management and its capacity to adapt to evolving challenges and emerging threats.

3.3.4. Quantitative Data Collection

Secondary data on flood events, impacts, and response efforts were collected from a variety of sources, including the Pakistan Meteorological Department (PMD), the Flood Forecasting Center (FFC), research institutions, government agencies, international organizations, and local news media. The data included comprehensive information on flood extent, affected areas, casualties, economic losses, and the response efforts undertaken by government agencies, non-governmental organizations, communities, and individuals. This data was obtained from official reports, databases, historical records, published studies, and news articles, ensuring a wide range of perspectives and sources. The data collection process aimed to capture the full scope and complexity of flood events in Pakistan, including their impacts on communities, infrastructure, and the economy, as well as the effectiveness of response efforts at different levels of government and society.

3.4. Data Analysis Techniques

In this comprehensive research study, several qualitative data analysis techniques were meticulously employed to synthesize, interpret, and derive actionable insights from the extensive information collected on flood management. Firstly, thematic analysis was utilized as a foundational method to identify, analyze, and report patterns, known as themes, within the qualitative data gathered from a wide array of sources, including policy documents, interviews, and detailed case studies. This systematic approach enabled researchers to delve deeply into the material, facilitating a thorough and comprehensive understanding of the prevailing challenges faced by practitioners in the field, the effective strategies that have emerged over time, and the best practices in flood management observed across the examined texts. Importantly, this analysis also highlighted the unique geographical and climatic factors that contribute to flooding in different regions, allowing for a more tailored approach to flood management.

Content analysis was systematically applied to categorize and quantify the information found in policy documents, media reports, and public statements from relevant agencies. This method proved instrumental in identifying and emphasizing recurring ideas and messages concerning disaster response in Pakistan, particularly in the context of its unique socio-political landscape. By dissecting the content, the researchers were able to pinpoint not only the prominent themes but also the underlying narratives that shape public perception, policy-making processes, and community preparedness initiatives. This analysis illuminated how media portrayals and policy frameworks influence local responses to flooding and disaster risk reduction.

The incorporation of comparative analysis further enriched the study by enabling the juxtaposition of different sources of information, including comparisons across various regional responses to flooding. This facilitated insights into the effectiveness of various flood management strategies employed in different contexts, thereby highlighting existing gaps that require immediate attention. By contrasting different viewpoints, methodologies, and case studies, researchers were able to draw more nuanced conclusions about what works and what does not in practice, while also considering cultural and socio-economic factors that play a critical role in disaster response.

Narrative analysis was employed to interpret the rich stories and lived experiences documented in situational reports, interviews with affected individuals, and community testimonials. This method provided essential context and depth to the quantitative data collected, allowing for a more holistic view of the social impacts of flood events on affected communities. By focusing on individual narratives, the research captured the human element behind the statistics, illustrating how flood events disrupt lives, livelihoods, and community resilience. This emphasis on personal stories not only humanizes the data but also serves to inform policymakers about the real-world implications of their decisions. Together, these analytical techniques contributed to a richer, more nuanced understanding of the complexities surrounding flood management and the urgent need for effective disaster response strategies in vulnerable regions, ultimately aiming to foster resilience and enhance preparedness for future flood events.

The qualitative data was analyzed within the context of the case study of the NEOC, allowing for a deeper understanding of the specific challenges, opportunities, and lessons learned. This involved examining the qualitative data in relation to the specific context of the NEOC, identifying how the findings relate to the case study, and drawing conclusions about the implications for flood management in Pakistan.

3.5. Ethical Considerations

Ensuring that the data acquired is precise, dependable, and devoid of mistakes or inconsistencies is crucial for doing rigorous research. This is known as data integrity. To ensure data integrity in this study, a number of steps were done. Initially, data verification was carried out using a variety of techniques, such as cross-referencing data from various sources, comparing data points to ensure consistency, and carrying out data cleaning procedures to find and fix mistakes. Data validation methods were also put in place to make sure that the gathered data complied with certain requirements and standards. These procedures included resolving any abnormalities and verifying completeness, correctness, and consistency. Standardized processes and terminology were used to guarantee uniformity in data gathering techniques, reducing variability and improving data dependability. In addition, the methodical and impartial use of data analysis methodologies ensured that the conclusions were supported by the available data and prevented bias. Reliability and validity of the results were ensured by carefully using appropriate data analysis techniques that were chosen depending on the kind of data and the research topics.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Review of Existing Flood Management Policies and Strategies in Pakistan

In a comprehensive review of four plans and policies related of flood management in Pakistan we have identified certain gaps and challenges that seemingly have an impact on the disaster preparedness and response mechanisms. The analysis underlines crucial areas for improvements, from early warning systems down to community-level involvement and institutional coordination in real-time data dissemination. These plans and policies are largely reactive and include little in the way of long-term risk-reduction strategies, despite recognition of many aspects of flood risks. Other issues, such as encroachments on floodplains by urbanization, very unsatisfactory infrastructure, and weak governance at the district level, further increase the vulnerability of many areas to flooding. In filling these knowledge gaps and providing appropriate proactive measures, Pakistan can make a quantum leap in its capacity for flood management and provide far superior protection for communities exposed to this hazard.

4.1.1. National Flood Protection Plan IV (FFC 2024):

Table 5: *National Flood Protection Plan IV (FFC 2024)*

Gaps	Challenges	Impact
Financial Constrains	Inadequate funding (Umbrella PC-I not approved due to lack of funds).	Delays in implementation of critical flood protection infrastructure.
	50:50 funding split between federal and provincial governments, leading to budgetary issues.	Inconsistent allocation of funds and slow progress in flood protection efforts.
Administrative and Institutional Challenges	Bureaucratic delays in approvals for updated plans and sub-projects.	Slow implementation and delayed response to flood risks.
	Weak coordination between federal and provincial agencies despite multiple consultations.	Ineffective collaboration, leading to inefficient implementation of flood protection plans.

Technical and Structural Gaps	Initial focus on flood protection, lacking an integrated flood risk management (IFRM) approach.	Limited coverage of risks such as flash floods, urban flooding, and hill torrents.
	In-sufficient capacity for implementing non-structural measures (e.g., early warning systems, NbS).	Delay in setting up effective early warning systems and nature-based solutions.
Environmental and Social Considerations	Overemphasis on structural interventions (e.g., dikes, spurs) with limited attention to non-structural solutions.	Missed opportunities to utilize nature-based solutions and community-led initiatives.
	In-adequate community involvement and lack of gender-informed strategies.	Vulnerable populations are often overlooked in planning and implementation.

While going through the document of National Flood Protection Plan IV, there have been a number of gaps and challenges that resulted in failure to successful implementation and management. Financial constraint is one major issue; insufficiency of funds has led to delay in the development of much-needed infrastructure; original cost was estimated at Rs 332.246 billion, whereas Umbrella PC-I for implementation was not approved due to the non-availability of funds, resulting in incomplete projects. Moreover, the 50:50 sharing between federal and provincial governments usually results in delays in clearing the backlog because the provinces have budgetary constraints that limit them from making available the required funds on a continuous basis. The administrative and institutional challenges further complicate this, where the bureaucratic delays in the approval process of the updated plan and sub-projects have considerably delayed its finalization, with ongoing approvals continuing till 2024. Coordination at the level of federal and provincial agencies has also been slow, notwithstanding repeated stakeholder consultations, which has emerged in the form of weak coordination for effective implementation. There are also some technical and structural gaps: On the technical side, the plan was oriented to flood protection, rather than Integrated Flood Risk Management-IFRM-involving flash floods, hill torrents, and urban floods. It is because of this narrowness of focus those necessary non-structural measures such as early warning systems and telemetry systems, which provide warnings to lower-lying areas well in advance in time for disaster response, have been included belatedly. Moreover, there is a need for non-structural measures from the plan, including nature-based solutions and early warning systems. In any case, this is restricted because some infrastructures and technological resources are not in place to reinforce it strategically. It is also an environmental and social issue; during its initial years, NFPP-IV was highly reliant on the structural measure involving dikes and spurs, while less consideration has been given to non-structural measures and the participation of the communities. Equally, there is a marked absence of effective social inclusion and gender-informed strategies in flood management that would risk the positions enjoyed by the local communities in rural and vulnerable areas. Finally, the evolving risks brought about by climate change have opened new challenges-after all, the original NFPP-IV had been designed prior to the 2022 floods which were to highlight issues of flash flooding and coastal flooding that were not taken into adequate consideration. In this light, the need to significantly revise the plan is felt necessary due to changing flood patterns and evolving climate-related hazards. The gaps and challenges demonstrate that while NFPP-IV came out with a very ambitious approach towards flood protection, the delays in funding, lattice, and institutional capacity and inadequate focus on non-structural measure issues are still an impediment towards success. These are areas that should be addressed if the flood management strategy in Pakistan is to work successfully.

4.1.2. Monsoon Contingency Plan (PDMA 2022):

Table 6: *Monsoon Contingency plan (PDMA 2022)*

Gaps	Challenges	Impact
Coordination Challenges	Fragmented communication between agencies.	Delayed resource mobilization and decision-making during floods.
	Slow response to early flood alerts.	Increases in flood damage due to delays in action.
Resource Limitations	Inadequate equipment and infrastructure at the local level.	Insufficient preparedness during high-risk periods.
	Lack of financial resources, especially at the district level.	Failure to implement preventive flood management measures.
Operational Gaps	Reactive approach to flood management rather than integrated risk management.	Recurring damage and inadequate mitigation efforts.

	Inconsistent application of early warning systems.	Vulnerable populations not receiving timely warnings, leading to avoidable losses
Data and Technology Issues	Insufficient use of modern technology (e.g., satellite monitoring, remote sensing).	Inefficient flood prediction and response mechanisms.
	Poor data-sharing mechanisms between federal and local authorities.	Delayed responses and misallocation of resources during crises.
Community involvement	Limited community engagement in disaster preparedness.	Local populations are not sufficiently informed or prepared for floods.
Institutional Weakness	Weak local implementation capacity and governance issues.	Inability of local governments to effectively execute the contingency plan.
	Over-reliance on external aid during flood events.	Undermines local capacity-building and long-term sustainability in flood management.

A close view of the Monsoon Contingency Plan PDMA 2022 depicts a number of gaps and challenges that are responsible for the failure to successfully implement and manage flood controls. The obvious deficiencies relate to streamlined coordination among various agencies such as PDMA and NDMA for flood management, which work within their respective silos. This results in delays in decision-making and mobilization of resources. Whereas early warning systems are in place, without proper communication at the federal, provincial, and district levels, response to flood warnings is less prompt. Similarly, most regions are found to have insufficient resources concerning equipment necessary for rescue operations and flood mitigation due to poor preparedness facilitated during high-risk periods. Funding constraints worsen the situation, whereby a lack of sufficient financial resources, especially at the district level, prevents local authorities from taking precautionary measures that include repairs to the embankments or the construction of an advanced drainage system. Operational gaps are present, too, given that the contingency plan is more geared toward response rather than an integrated, proactive approach in the management of flood risks. This narrow approach to mitigation and resilience-building leads to repeated damage and losses. Moreover, the poor implementation of early warning systems ensures that timely warnings often are unable to reach the most vulnerable populations in time, which causes the loss of life and property that could have been avoided. Similar issues with data and technology also mar the plan. It does not tap into modern satellite-based monitoring of areas in real-time and data analytics applications for flood prediction and management. Secondly, even when such flood information is available, there are usually inadequate ways through which such information can be shared between the federal and local agencies. This causes a delay in response and distribution of resources. Also, the paper has failed to present involvement and preparedness among communities. The plan does not seek community involvement in disaster safety and response; therefore, in areas where the risk is high, local communities are not yet educated or trained concerning the procedures that should be followed in case of an emergency. Sixth, vulnerable groups include women, children, and the elderly who often are never allowed to attend the flood preparedness training or awareness programs, hence a gap in evacuation and relief. In addition to that, the plan does not amply address the impacts of climate change for failure to propose long-term measures necessary for mitigating the effects of intensified and unpredictable flood patterns. These reasons include an inability due to poorly developed training, poor governance, and a lack of resource decentralization. Finally, overreliance on external help in cases of serious flooding event tends to undermine the process for building local capacities and sustainability.

4.1.3. Monsoon Contingency Plan (NDMA 2024)

Table 7: *Monsoon Contingency Plan (NDMA 2024)*

Gaps	Challenges	Impact
Coordination Issues	Fragmented communication between federal, provincial, and district levels.	Delays in decision-making and response.
Resource Gaps	Lack of essential rescue equipment and infrastructure, particularly in remote areas.	Inadequate preparedness and slower flood management responses.
Operational Shortcomings	Slow response to early warnings and a reactive approach to flood management.	Increased loss of life and property due to delayed evacuation and response.

Community Engagement	Limited community participation in flood preparedness and response.	Poor evacuation practices and lower levels of local preparedness.
Environmental Challenges	Urban encroachment and poorly maintained flood defences.	Increased urban flooding and structural failures during monsoon seasons.
Institutional Weakness	Lack of local disaster management capacity and over-reliance on armed forces.	Inability to manage disasters at the local level and overburdening national resources.

Gaps and challenges in successful implementation and management of floods became apparent after going through the Monsoon Contingency Plan, 2024. At the federal, provincial, and district levels, coordination is usually disjointed within disaster management authorities. While the NDMA issues national guidelines, on-ground implementation lacks proper and streamlined coordination between the provinces and districts. This again represents a large number of stakeholders that include provincial governments, local administrations, and several federal agencies. The absence of a single command system delays the decision-making process, mobilization of resources, and communication at the time of the flood. There is also a serious deficiency in the availability of crucial rescue and flood management equipment at various places, especially in the far-flung areas of the country. The report identifies that there is a continued need for additional boats, outboard motors, earth-moving machinery, and standby power supplies. The sometimes-insatiable financial needs in operations lead to a fall in financial availability for the local governments and disaster management authorities. The plan is pegged on the government allocations and the districts are generally underfunded hence cannot create total preparedness. Whereas there are provisions for early warning systems the actions towards such warnings are pretty slow especially at the local level. While the document calls for the timely dissemination of information, many communities vulnerable to hazards do not receive their warnings in time. It focuses a great deal on response rather than proactive measures that have very scant long-term risk reduction strategies, leaving many parts of the country prone to flooding time and again. The plan establishes that real-time dissemination systems are urgent, especially in far-flung and high-risk areas. There are, however, technological limitations to establishing automated weather monitoring or river flow monitoring stations. In addition, crucial flood data accumulated with one agency is often not effectively shared between necessary participants; this causes delays in decision-making and resource allocation. Disaster preparedness at the community level has not been included in this plan. It focuses on raising public awareness, but there is no actual participation of the people at the grass-roots level. Real participation with the local populace is so minimal that appropriate scenarios for evacuation cannot be simulated and preparation for it would always remain low. Women, children, and the elderly-are not effectively captured by disaster preparedness programs, hence evacuation procedures and emergency relief operations contribute to the burden. Urban encroachment on floodplains continues to increase the risk of flooding in urban areas. While the blueprint asks for the removal of these encroachments, the enforcement is still weak and, therefore, in every monsoon season, there are repeated problems concerning this aspect. Similarly, most of such flood protection structures including bunds and dikes, are outdated and poorly maintained. Though the plan identifies this requirement, yet the timeframe or resources for overcoming such weaknesses have not been provided. While the plan recognizes the role of climate change in increasing flood risks, the concrete measures with respect to long-term climate adaptation remain few, with much of the focus on short-term responses. Further, institutional weaknesses remain part of the problem; disaster management at the district level is crippled by weak governance and a lack of trained personnel, seriously affecting the efficacy of flood management. The plan lastly moves from this regular schedule to include seeking help from armed forces in responding to floods, over-reliance on which indicates absence of local capacity to manage disasters on their own.

4.2.Global Best Practices

4.2.1. Community-Centric Flood Management Initiatives

The flood-prone country of Bangladesh, has effectively implemented community-centric flood management policies that empower local communities to proactively take part in disaster preparedness and response.

4.2.1.1.Case Study of Leading Components of Bangladesh's Policy:

Flood Shelters for Community: Government of Bangladesh has extensively constructed multipurpose flood shelters in flood prone localities. These shelters are designed to accommodate communities during floods and are provided with essential supplies such as food, water, and first aid kits. Community members are trained to manage these shelters enabling them to be well-prepared for emergencies.

Communication of Early Warnings: The country has established a resilient and reliable advance warning and information system that makes use of both high-tech solutions and traditional communication means. Early warnings are transmitted through mobile phones, community radio, and loudspeakers. Local volunteers undertake the vital responsibility of propagating warnings and helping with evacuations.

Community-Based Organizations (CBOs): Bangladesh's flood management policy predominantly depends on the involvement of CBOs. These organizations work at the grassroots levels, educating communities about flood risks and preparedness. In addition, CBOs perpetually liaise with government institutions to ensure that relief efforts are effectively focused.

Application in Pakistan:

Community Engagement: Pakistan can adopt Bangladesh's success in community-based flood management by establishing similar CBOs. These organizations will certainly be pivotal in propagating awareness, executing coordinated evacuations, and managing local flood shelters.

Flood Shelters: Establishment of flood shelters in vulnerable regions of Pakistan will provide safe havens for communities during disasters. These shelters will also serve as centres for disaster trainings and community meetings.

4.2.2. Nature-Based Solutions and Ecosystem-Based Adaptation

Nature-based solutions (NbS) and ecosystem-based adaptation (EbA) are emerging as popular sustainable approaches to flood management. These strategies make use natural processes and ecosystems to reduce flood risks while providing fringe benefits such as biodiversity conservation and climate resilience.

4.2.2.1. Case study of China: The Sponge City Initiative

China has launched the "Sponge City" initiative, which aims to enhance urban flood resilience through nature-based solutions. The concept involves designing selected portions of land in urban areas to absorb and store rainwater which in the process reduces the risk of flooding and improves water management.

Key Features:

Green Infrastructure: The initiative advocates the use of green roofs, permeable pavements, and urban green spaces to absorb rainwater and reduce surface runoff. These features help reduce urban flooding by increasing the city's capacity to manage heavy rainfall.

Wetlands and Lakes: Urban wetlands and lakes are integrated into the town planning to store excess rainwater and provide flood protection. This enhances urban biodiversity and provides recreational spaces the city population.

Water Recycling: The rainwater accumulated is often filtered and reused for non-consumption purposes such as irrigation and street cleaning. This reduces demand pressure from municipal water supplies.

Figure 4.2.1: *An example of a true sponge city project. Sanya Dong'an Wetland Park, Sanya, Hainan Province, China / Turenscape (Jared Grenn, 2021)*

Application in Pakistan:

Urban Flood Management: It is imperative for Pakistan's rapidly growing cities to adopt measures based the Sponge City principle. By promoting green infrastructure and increasing rain water retention in urban areas, cities like Karachi and Lahore will be able to reduce their vulnerability to flash floods and improve overall water management.

Ecosystem-Based Adaptation: In its rural and agrarian regions, Pakistan must implement ecosystem-based adaptive measures like mass reforestation and the restoration of natural floodplains to mitigate flood risks and increase resilience to climate change.

4.2.3. Multi-Layered Defense Strategies

Many countries are adopting multi-layered defense strategies to manage flood risks. This approach involves the integration of multiple lines of defense, ranging from natural barriers to engineered structures and community-based measures. The idea is to create redundancy in flood protection, ensuring that if one layer fails, others will still offer protection.

4.2.3.1. Case study of United States: The Mississippi River Management

The United States has developed a potent and innovative flood management strategy for the Mississippi River one of the world's leading river systems. The policy includes a combination of levees, floodways, reservoirs, and wetlands restoration to manage to combat floods.

Key Features:

Levees and Floodways: An extensive network of levees and floodways channels floodwaters away from population centres. During peak floods, floodways are operated to divert excess water into pre-designated areas reducing pressure on levees and minimizing the risk of breaches.

Wetland Restoration: Accepting the importance of natural barriers, the U.S. has invested in the restoration of wetlands along the Mississippi River. These wetlands act as natural filters, absorbing floodwaters and reducing downstream flooding.

Reservoirs and Dams: A cascade of reservoirs and dams along the river provides additional flood control by storing excess water during heavy rains and releasing it gradually to forestall downstream flooding.

Figure 4.2.2: *Aerial view of the four structures of the Mississippi River Old River Control Structure, looking downstream to the south. Water flows from the Mississippi River through the four structures, to the Atchafalaya River (right). Image credit: U.S. Army Corp*

Application in Pakistan:

Resurrection of Wetlands and Floodplains: Pakistan needs to implement similar policies by resurrecting wetlands and floodplains in key regions along the Indus River. This will not only provide natural protection from intense flooding but will also benefit biodiversity and improve water quality.

Floodways and Diversions: Constructing floodways and diversion channels in flood-prone areas will help manage excess water during peak floods thereby protecting vulnerable populations and infrastructure.

4.2.4. Integrated Flood Management (IFM)

The Netherlands has developed one of the most advanced flood management systems in the world, mainly because of its Integrated Water Resource Management (IWRM) approach. This strategy is pivoted on integrating human needs with environmental sustainability, ensuring that flood management measures are effective and ecologically responsible at the same time.

4.2.4.1. Case study of IWRM in the Netherlands:

“Room for the River” Initiative: This project constitutes creating space for rivers to natural flood, reducing the pressure on dikes and embankments. The project includes measures to achieve goals like lowering floodplains, relocating dikes, and creating water retention areas. By enabling rivers to overflow into designated areas, the Netherlands has reduced the risk of devastating floods in population centres and agricultural zones.

Smart Dikes and Flood Bulwarks: The Netherlands has constructed "smart" dikes and flood barriers equipped with sensors that monitors structural integrity in real-time. These systems provide early warnings of impending failures, enabling timely maintenance and corrective measures.

Water Boards: The Netherlands' governance structure includes regional Water Boards, which are responsible for localized water management. The boards function independently of the central government ensuring that flood management is customized to the peculiar needs of respective regions. The decentralized nature of the Water Boards enables rapid responses and quick decision-making during flood emergencies and before.

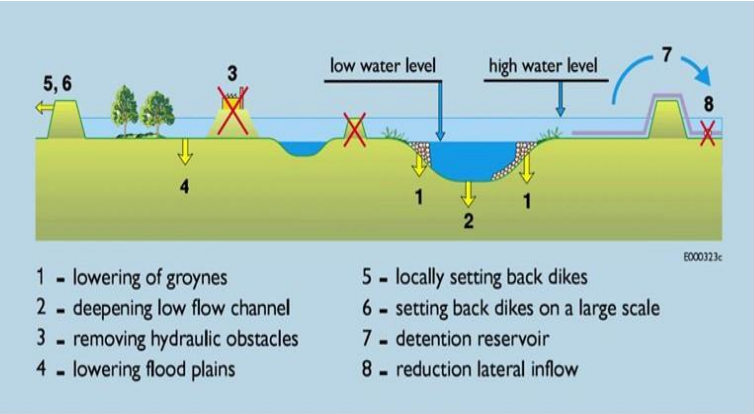

Figure 4.2.3: *Eight different Room for the River measures (Silva et al., 2001)*

Application in Pakistan

Adaptive Infrastructure: Pakistan could revolutionize its flood management by subscribing to adaptive infrastructure strategies, particularly in areas prone to riverine flooding. Planning a creating dedicated floodplains and water retention areas could help considerably reduce the effects of floods in the Indus Basin.

Decentralized Water Management: Creating regional water management authorities in Pakistan could improve the coordination and effectiveness of flood management at the local levels. These authorities may be empowered to make decisions based on regional situations and needs on the lines similar to the Dutch Water Boards.

4.2.5. Innovations in Flood Forecasting and Response

Japan is another global leader in flood management, which has harnessed the latest technology to increase disaster preparedness and response capabilities. The country's approach combines high-tech solutions with traditional infrastructure, creating a robust system capable of managing both riverine and coastal floods.

4.2.5.1. Case study of Technological Innovations in Japan:

Super Levees: Japan has constructed "super levees," which are broader and more resilient against erosion than conventional levees. These structures are designed to withstand the huge pressure of floodwaters, mitigating the risk of breaches.

Automated Floodgates: In urban areas, Japan has implemented automated floodgates that can be activated remotely to prevent the ingress of water into subway systems and underground facilities. These floodgates are controlled by a centralized system that monitors water levels and weather conditions in real-time.

Flood Simulation Models: Japan uses advanced flood simulation models to predict the effects of likely flood situations. These models are dovetailed into urban planning processes, ensuring that new developments are designed with flood risks in mind. The simulations help identify vulnerable areas and suggest the construction of flood defenses.

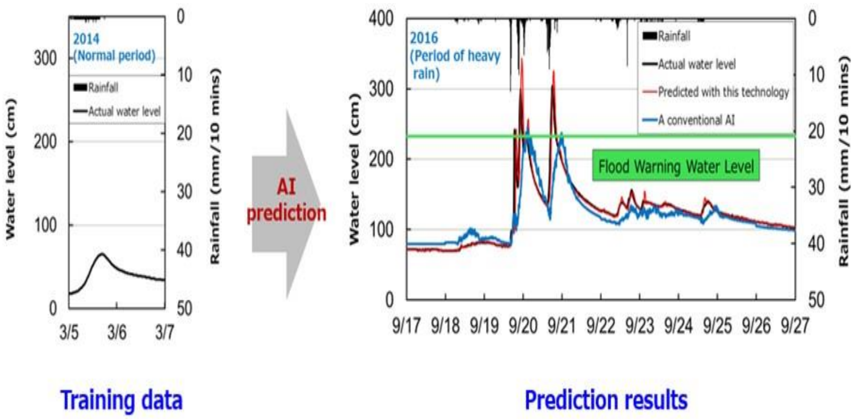

Figure 4.2.4: Japan: Fujitsu develops AI disaster mitigation technology to predict river flooding with limited data (Fujitsu,2019)

Application in Pakistan:

Technology Integration: Pakistan can improve its flood management strategies by adopting similar technologies, such as automated floodgates in urban areas prone to waterlogging. Investing in advanced simulation models can also improve flood risk assessments and facilitate better urban planning.

Robust Infrastructure: The development of more resilient and robust infrastructure, similar to Japan's super levees will certainly protect critical areas in Pakistan from extreme flooding especially along the Indus River.

4.2.6. International Collaboration and Knowledge Sharing

International collaboration is a very important factor in evolving flood management strategies. By learning from the experiences and innovations of other countries, Pakistan can adopt best practices and avoid problems faced by other countries.

4.2.6.1. Global Facility for Disaster Reduction and Recovery (GFDRR)

GFDRR is a worldwide collaboration that facilitates developing countries better understand and take steps to mitigate their vulnerability to natural disasters like floods. It accords technical assistance, monetary support, and knowledge-sharing platforms to support the implementation of disaster risk management policies. Pakistan has benefited from GFDRR's initiatives, which have helped advance the country's flood risk assessment and early warning systems.

By proactively participating in such global initiatives, Pakistan can access modern technologies, skills, and funding to improve its flood management systems. Moreover, cooperation with neighboring countries, especially those with shared river systems, is vital for effective flood management. Collaborative efforts in data sharing, river management, and disaster response can result in better coordinated and impactful flood management across borders.

4.2.6.2. The Sendai Framework for Disaster Risk Reduction

Adopted in 2015, the Sendai Framework is the first major agreement of the post-2015 development agenda, with seven targets and four priorities for action. It underscores the importance of understanding disaster risk, strengthening disaster risk governance, investing in disaster risk reduction for resilience, and enhancing disaster preparedness for effective response.

The framework calls for a "whole-of-society" approach, which unifies the involvement of governments, the private sector, civil society, and communities in disaster risk reduction efforts. For flood management, the Sendai Framework emphasizes the integration of risk assessments into planning processes, the development of comprehensive early warning systems, and the promotion of resilient infrastructure.

Application in Pakistan

For Pakistan, bringing its flood management strategies in line with the Sendai Framework can provide a comprehensive and structured approach to reducing flood risks. This would entail reinforcing institutional frameworks for disaster risk reduction, increasing coordination among stakeholders and incorporation of risk reduction measures into national and local development planning.

4.2.7. Policy Recommendations for Pakistan

Based on analysis of global best practices and the present challenges faced by Pakistan, following recommendations are proffered to improve the country's flood management strategies.

4.2.8. Development of a National Flood Management Framework

Pakistan should develop an all-inclusive national flood management framework that bounds together structural and non-structural measures, contemporary technologies, and community-based initiatives. This framework should adopt measures as enumerated hereunder: -

- **Infrastructural Upgrades:** Invest in the reconstruction and modernization of existing flood protection structures such as dams, embankments, and drainage systems.
- **Technology Integration:** Incorporate AI, remote sensing, and real-time monitoring systems into the flood prediction and early warning regime.
- **Increased Coordination:** Define roles and assign responsibilities for federal, provincial, and local government authorities, for coordinated and swift responses to floods.
- **Community Engagement:** Promote community-based flood management initiatives that empower local populations to take an active role in flood preparedness and response.

4.2.9. International Collaboration

Pakistan needs to actively garner partnerships with international organizations and neighboring countries to enhance its flood management capabilities. This includes participation in global disaster risk reduction initiatives, sharing data and knowledge, and cooperation on cross-border river management.

4.2.10. Investment in Training and Capacity Building

For sustainable improvements in flood management, Pakistan must invest in education and capacity building. The scope of training should cover government officials, disaster management experts, and local communities in modern flood management techniques and technologies. Additionally, public information and awareness campaigns should be launched to educate the population about flood risks and preparatory measures.

4.2.11. Summary and Lessons for Pakistan

The global examples of flood management practices underscore the necessity of a multi-dimensional strategy that combines technology, community participation, and natural solutions. Pakistan can derive following valuable takeaways from these examples: -

- **Integrated Policies:** Developing an integrated policy to flood management that combines structural and non-structural actions, innovative technologies, and community-centric initiatives is vital for achieving resilience.
- **Technological Advancements:** Harnessing latest technologies such as AI, remote sensing, and hydrological modelling can considerably enhance Pakistan’s flood forecasting and response capabilities.

- **Community-Centric Management:** Engagement of local communities in flood management, as prevalent in Bangladesh and the Netherlands, is vital to ensure the effectiveness and sustainability of flood risk reduction.
- **Nature-Based Solutions:** Implementation of nature-based solutions and ecosystem adaptations can provide sustainable flood protection. Moreover, this will also accrue environmental and social co-benefits.

4.3. Role of NEOC in Flood Hazard Assessment and Management

As enunciated in preceding parts of this study, it aims at evaluation of the effectiveness of the National Emergency Operations Center (NEOC) in flood hazard assessment and management in Pakistan. Using a wide range of data from NEOC advisories, National Disaster Management Authority (NDMA) Situation Reports (SITREPs), Provincial Disaster Management Authorities (PDMAs), in addition to rainfall and river discharge records, an attempt has been made to carry out a comprehensive analysis of the events. The study analyses the accuracy and responsiveness of early warning systems, the impact of floods on infrastructure, economy, and human displacement caused by the 2023 floods in comparison with previous incidents in the regions under study. The findings reveal that whereas NEOC has made considerable headway in flood management, challenges remain specifically with regards to the accuracy of forecast and public response mechanisms. Based on this evaluation, certain recommendations have been made to increase operational effectiveness for NEOC's and inculcate readiness and resilience for vulnerable communities against impending flood hazards of the future.

4.3.1. Background

The geographic regions of Pakistan are extremely vulnerable to a broad spectrum of natural disasters due to its diverse geography and peculiar location. Foremost among these vulnerabilities is the susceptibility to floods, both in elevated topographies owing to glacial outbursts and flash floods and river basins because of the monsoon climate coupled with elevated river inflows from northern (north-western) mountainous regions. Floods have repeatedly been the cause of considerable loss of life and material assets which in turn translates into economic and social instability. In order to provide timely forewarnings and to mitigate the damage caused by such disasters, the National Emergency Operations Center (NEOC) acts as a focal entity for spearheading disaster response and coordinating management efforts in the whole country. Conceived and established under the aegis of NDMA, NEOC is entrusted with monitoring, assessment and timely dissemination of information related to natural and man-made disasters, in order to garner timely and effective response to mitigate the impact of these disasters.

The floods of 2023 were unusually intense, which subjected the Sutlej River areas and DG Khan Region to devastating floods. These floods proved to be a test case for the efficacy of NEOC and other disaster management agencies. An incisive study of these floods and response thereof provides a clear insight into the effectiveness of prevalent flood management policies and identifies gaps required to be spanned through improvements in the system and strategy.

4.3.2. Qualitative Data Analysis (Rainfall Amount and River Discharge)

4.3.2.1. Rainfall Analysis

- **July-August 2023 Rainfall Overview**

During the monsoon season of 2023, regions across Pakistan experienced abnormally heavy rainfalls. Punjab province in general and areas of Sutlej River basin and DG Khan in particular were severely affected by this excessive rainfall.

Rainfall Statistics:

a. Punjab Province experienced an average rainfall of 250 mm during July and August 2023, which is approximately 40% above the seasonal average of previous years vis-à-vis the available records.

b. Sutlej River Basin recorded an aggregate rainfall of 300 mm, considerably higher than the average of 200 mm, causing increased runoff into the river system.

c. DG Khan Region experienced a total rainfall of 280 mm, exceeding the average by 35%, mainly because of continuously heavy rainfall over short spans of time.

Contributing Factors:

Monsoon Depressions: A large number of low-pressure systems developed over the Bay of Bengal and during their movement northwestward caused intense rainfall over northern regions of Pakistan.

Climate Change Impacts: Heightened surface temperatures of seas caused change in monsoon patterns contributing to the intensification and unpredictability of rainfall instances.

- **Impact on Sutlej River and DG Khan**

Sutlej River: The more than usual rainfall resulted in rapid swelling of the river, exceeding danger levels at most of the monitoring points. As the catchment areas received incessant rainfall over many days, it resulted in reduction in the absorption capacity of the and hence increased surface runoff.

DG Khan: The areas in the proximity of the Suleiman Range foothills, received intense flash floods as torrential rains led to swelled stream and nullahs descending from the mountains, overflowing the low-capacity waterways and drainage systems.

4.3.2.2. River Discharge Analysis

- **Sutlej River Discharge**

Discharge Data:

Ganda Singh Wala Monitoring Station reported peak discharge levels reaching 270,000 cusecs on August 15, 2023, classified as an 'exceptionally high flood' situation.

Head Sulemanki recorded discharge levels of 220,000 cusecs on August 17, 2023, leading to inundation of adjoining agricultural lands and settlements.

Analysis:

The surge in discharge was mainly due to upstream rainfall and releases of water from upstream reservoirs. The inflow of water exceeded the capacity of the river thereby causing multiple breaches in embankments and in turn extensive flooding.

Coordination with upstream water authorities, which is critical for response and management, faced multiple challenges, as unexpected/unprecedented releases complicated the flood situation.

- **DG Khan Flood Event**

Discharge Data:

Local streams such as Wadore and Sanghar Nullahs experienced discharge levels exceeding 25,000 cusecs, well over their maximum capacities, leading to torrential floods.

Indus River, adjacent to DG Khan, achieved high water levels but did not overflow considerably, signifying that local rainfall and runoff were the main cause of the flooding.

Analysis:

Intense nature of rainfall over short periods caused rapid accumulation of water in low-lying areas, exceeding the capacity of existing drainage infrastructure.

Absence of requisite flood channels and slow actions with regards to water diversion measures worsened the situation, causing widespread damage.

4.3.2.3. Impact Assessment

- **Infrastructure Loss (Damages to Roads and Bridges)**

Sutlej Region:

Roads: Approximately 150 km of road segments were damaged, including some major highways providing access of rural areas to urban centers. Route that affected the most was Kasur-Ferozepur Road. Damage to the road infrastructure disrupted transportation and adversely affected relief efforts.

Bridges: Two of the improtant bridges on Sutlej River, namely Head Sulemanki Bridge and Islam Headworks Bridge were partially damaged, causing temporary suspension of traffic and affecting cross-river connectivity.

DG Khan Region:

Roads Infrastructure: About 100 km of roads were destroyed or extensively damaged especially in the Taunsa Sharif area, severing the connectivity of several communities and impeding rescue operations.

Bridges: Several minor bridges on local streams were either swept away or damaged by the forceful floodwaters, cutting off access to remote villages.

- **Impact on Buildings and Other Structures**

Residential Structures:

Sutlej Region: Over 5,000 residential units were reported damaged, with 1,500 completely destroyed, resulting in displacement of thousands of residents.

DG Khan: Approximately 3,200 residential houses were damaged, with 900 rendered completely uninhabitable.

Public Infrastructure:

Schools: Over 150 educational institutions were affected, delaying the resumption academic activities and affecting over 50,000 students.

Healthcare Facilities: 25 hospitals and clinics were damanged, diminishing the already meager healthcare capacity during and after the floods.

Agricultural Losses: Large swaths of farmland came under water, with approximately 200,000 acres of standing crops destroyed in the Sutlej basin and more than 150,000 acres in DG Khan, adversely affected food security and livelihoods of landowners and tillers alike.

- **Economic Cost**

Direct Economic Losses

Sutlej Region:

Damage to Infrastructure: A whooping sum of Rs. 20 billion was incurred on repair & reconstruction of roads network, bridges, and other government infrastructure.

Losses to Agricultural Sector: In terms of destroyed crops and degradation of soil for immediate farming a staggering sum of Rs. 15 billion was estimated.

Losses to Private Property: Damage to private residences and businesses was estimated to be Rs. 10 billion.

DG Khan Region:

Infrastructure Damage: Requirement of funds amounting to RS. 12 billion was estimated for repair and reconstruction of essential services.

Losses to Agricultural Sector: An aggregate loss of Rs. 8 billion was estimated owing to damage sustained by standing crops, trees and soil.

Losses to Private Property: Losses were estimated to be upwards of Rs. 6 billion.

Indirect Economic Losses

Loss of Livelihoods: Thousands of individuals lost their sources of income due to destruction of workplaces, agricultural land and disruption of commercial and economic activities.

Surge in Healthcare Costs: Expenditure on healthcare increased considerably owing to flood-related diseases and injuries putting extra burden on both public and private health systems and affected individuals.

Disruption of Education Activities: Long-term economic impacts due to interruption in education, affecting human capital development.

Migration and Strain on Urban Centres. Populations displaced by floods migrated to urban areas thereby increasing burden on urban infrastructures and resources in turn leading to economic and social outfalls.

Human Displacement

Sutlej Region:

Displacement of People: Over 60,000 people were displaced who were forced to seek shelter in relief camps and with relatives in unaffected areas.

Relief Camps: About 45 camps were established providing basic necessities. However, in more cases than not, overcrowding and shortage of resources were reported.

DG Khan Region:

Displacement of People: 40,000 people were reported to have evacuated, with 30 relief camps set up to accommodate the internally displaced.

Vulnerable Populations: Vulnerable members of population e.g Women, children, sick and the elderly made up a considerable portion of the displaced people and the displacement enhanced risks and vulnerability attributed to such groups.

Social Impact

Health Challenges: Outbreaks of waterborne diseases such as cholera and dysentery were reported, aggravated by absence of facilities and poor sanitation in flood affected areas.

Psychological & Mental Health Issues: Many individuals, especially children, experienced psychological distress due to loss and disruption, with limited or no access to mental health support.

Educational Setbacks: Displacement of people away from their respective schools led to prolonged discontinuation of classes, affecting educational continuity and performance.

Security Concerns: Displacement and chaos made room for crime. Instances of theft and violence were reported in some relief camps, underscoring the need for better security and management.

4.3.2.4. Historical Flood Events in Sutlej and DG Khan

- **Flood Events in Sutlej**

2010 Floods: Sutlej River witnessed severe flooding, with discharge levels reaching 250,000 cusecs accompanied by widespread devastation.

Comparison with 2023: The 2023 floods had relatively higher discharge levels but improved early warning systems and preparedness measure resulted in comparatively lower casualties despite comparable levels of physical damage.

- **Flood Events in DG Khan**

2012 Floods: DG Khan was extensively affected by instances of flash floods caused by torrential rains, resulting in considerable infrastructural disruption and loss of life.

Comparison with 2023: 2023 flood event saw improved and coordinated response efforts and swift mobilization of resources, reducing the immediate impact on human life. However, infrastructure vulnerabilities remained as high.

4.3.2.4. Evaluation of Early Warning Systems (Timeliness, Accuracy, Public Response)

- **Analysis of NEOC Advisories**

Issuance Timing: NEOC issued flood warnings for the Sutlej River on August 10, 2023, 5 days prior to peak surge in water flow which provided important warning time for evacuation and preparation.

DG Khan Alerts: Flood alerts were issued on August 12, 2023, in advance of the major rainfall events. However, few areas reported delays in receiving in these warnings.

Effectiveness: The timely advisories enabled authorities to initiate evacuation plans and mobilize resources; however, logistic problems hampered the smooth execution of these operations in some areas.

- **Coordination with Local Agencies**

Inter-Agency Collaboration: NEOC coordinated with NDMA, PDMAs, and local government authorities to disseminate information and coordinate response actions.

Challenges:

Communication Gap: In some instances, delays and gaps in communication were noted between central and local agencies, adversely affecting response time.

Resource Limitations: Shortage of emergency response equipment and trained personnel in some areas hampered smooth execution.

- **Accuracy of Predictions (Comparison with Actual Events)**

Forecasts - Sutlej River: Forecasted water discharge data corroborated actual measurements, indicating reasonable accuracy in forecast for this particular area.

Rainfall Predictions - DG Khan: General predictions pointed to unusual rainfalls. However, localized excessive rains surpassed the forecast thereby resulting in relatively inaccurate estimations about the intensity of the floods.

- **Use of Technology and Data**

Employment of Hydrological Models: To achieve accuracy, advanced modeling techniques were employed, incorporating real-time data and historical trends which resulted in improving the prediction capabilities.

Use of Satellite Monitoring: Satellite imagery was used for detailed evaluation of weather systems and degree of floods which augmented planning and assessment capability.

Limitations: insufficiently equipped monitoring systems in far flung localities and non-inclusion of native knowledge adversely affected the accuracy of forecasts.

- **Public Response and Awareness**

Relay of Information: Alerts and warning were communicated through multiple media, i.e. television, radio, SMS alerts, and social media platforms for the sake of redundancy and as wide coverage as possible.

Community Engagement: Local government authorities conducted door-to-door alert campaigns and used Public Address systems in flood-prone areas to ensure communication of forewarning.

Response Results:

Compliance: Possible casualties were averted or reduced considerably as majority of affected populations responded well to the evacuation orders.

Non-adherence: Some residents were not readily willing to evacuate due to mistrust of the authorities, affiliation with the property, or obliviousness to the impending risks, leading to unnecessary hardships.

- **Awareness Campaigns**

Pre-Monsoon Actions: NEOC and related organizations conducted pre-monsoon awareness programs with specific emphasis on disaster preparations and response strategies.

Effectiveness: These initiatives improved general awareness but highlighted disparities in understanding and preparation levels between urban and rural segments of the population.

Recommendations:

Continuous Education: Once a year programs or spur of the moment initiatives may not bring plausible results and the desired levels of response and preparedness. In order to introduce a culture of quick response and preparedness year-long educational programs are recommended to be launched.

Inclusive Policies: There exists a wide spectrum of linguistic, ethnic, cultural and socio-economic diversity among populations even in every region. Sensibilities of all these diverse kinds need to be addressed for effective and convincing communication. For this, an inclusive communication policy based on diversity is required to be formulated.

4.3.3. Summary

The floods of 2023 served as a stark reminder of both the progress made and the ongoing challenges faced in flood management across affected regions. These devastating events notably illustrated the vulnerabilities present not only in existing infrastructure but also in socio-economic frameworks that are crucial for resilience. While significant improvements in monitoring systems and community engagement had been implemented since previous disasters, the current flood event resulted in the substantial displacement of approximately 100,000 individuals, leaving families and communities in dire situations. Additionally, the direct fiscal losses were estimated to exceed Rs. 60 billion, emphasizing the economic impact of such natural disasters.

The effectiveness of public responses to the floods varied widely among different regions, revealing a pressing need for enhanced public education and trust-building initiatives, which are essential for ensuring cohesive community action during emergencies. Critical gaps in infrastructure and technological capabilities were glaringly identified, underscoring the urgent need for sustained investment in durable flood defenses and advanced forecasting technologies that can provide timely warnings and aid in disaster preparedness.

Table 8: *Summarizing table of role of NEOC in flood forecasting*

Date	Location	Projection	Impact	Rainfall	River Flow	Real time event	Flood Model Accuracy
Jul 6, 23	Upper catchment of Sutlej, Ravi and Chenab	Heavy to very heavy rainfall expected with extremely heavy rainfall in upper catchments of Sutlej, Ravi, Chenab	Flash flooding expected in hill torrents of DG Khan; risk of high flow depending on releases from India	Extremely heavy rainfall forecasted for upper catchments	High flow expected, depending on releases from India in Ravi and Sutlej	Heavy rainfall observed, flash flooding occurred in hill torrents of DG Khan and local nullahs in North Balochistan	High: Projections validated by real-time data, flash floods occurred as expected in early July 2023
Jul 11, 23	Sutlej Region	Very high flows in Sutlej River downstream of Harike, inundation expected in low-lying areas	Inundation of low-lying areas, damage to crops, infrastructure at risk, hutments affected	250 mm rainfall recorded in July-August	Sulemanki reported 101,193 cusecs	River Sutlej flows exceeded projections, infrastructure damage reported, local evacuations executed	High: River Sutlej exceeded predictions; significant damage as expected in mid-July 2023
Jul 28, 23	Lower Sutlej Basin	High flood levels at Guddu and Sukkur Barrages, precautionary evacuations required	Severe flooding risk, precautionary evacuation required in lower basin areas	Heavy monsoon rains with 280 mm rainfall in DG Khan	Guddu and Sukkur barrages reached high flood levels	Flooding reached high levels, but evacuations mitigated casualties	High: Evacuations prevented casualties, flow levels matched projections in late July 2023

Aug 10, 23	Sutlej River	Danger levels expected to be exceeded, displacement of people anticipated	Flooding of roads, bridges, displacement of 60,000 people, extensive damage	Sutlej River basin recorded 300 mm rainfall	Sutlej River peaked at 270,000 cusecs at Ganda Singh Wala	Sutlej River surpassed danger levels, widespread damage reported	High: Flooding and displacement matched predictions in early August 2023
Aug 12, 23	DG Khan	Flash floods expected in DG Khan, infrastructure and local streams at risk	Local streams overflowing, flash floods, infrastructure damage, displacement of 40,000 people	Torrential rains, 280 mm recorded in DG Khan region	Local streams exceeded 25,000 cusecs, causing flash floods	Flash floods occurred in DG Khan, heavy infrastructure damage and displacement	High: Flash floods occurred as projected in mid-August 2023
Aug 16, 23	Sutlej River	Medium to high flows expected, risk of flooding in Sutlej River	Medium to high flow levels expected, vigilance needed, crops at risk	Moderate to heavy rainfall in catchment area	River flow exceeded danger levels at multiple points	Sutlej flows rose but proactive measures mitigated severe impacts	High: Proactive actions reduced damage as forecasted in mid-August 2023
Aug 24, 23	Sutlej Catchment Area	High flows forecasted due to reservoir releases from India, risks of heavy flooding	High flows forecasted due to Indian reservoir releases, increased flooding risks	High rainfall contributing to consistent high flows	Upstream releases caused high flows in Sutlej	High flows monitored; timely interventions helped minimize damage	High: Model predicted high flows, minimized damage in late August 2023

CHAPTER 5: RECOMMENDATIONS & CONCLUSION

5.1. Recommendations

Expansion in Monitoring: All remote and flood/ disaster prone areas need to be integrated with the monitoring network. To achieve this, number of meteorological and hydrological stations in high-risk remote areas need to be increased.

Technology Integration: Use of outmoded and conventional means for monitoring and forecast, though sometimes essential may not serve the purpose of accuracy and speed. There have been immense technological advancements in the field of machine learning and Artificial Intelligence which are being used globally for precise and dynamic prediction models. Harnessing these technologies will enhance the efficacy and accuracy of disaster warning and management system exponentially. At the same time, development of human resource capable of handling such advanced technologies is of pivotal importance for this integration to be meaningful and effective.

Increased Data Sharing: Collaboration of cross-border data sharing with upstream countries is essential for effective early warning. Unfortunately, the strained relations with our major neighbor make any meaningful collaboration extremely difficult. Nevertheless, for the sake of human safety, engagement with all neighbors including India is essential to mitigate the devastating impact of the floods.

Upgrade of Flood Defenses: The existing flood defense infrastructure has proven to be fragile and not sufficient to withhold the damage envisaged in the face of ongoing climate change and resultant floods. A comprehensive survey and assessment of existing infrastructure making use of modern techniques is essential to chalk out an upgrade plan. Eventually the embankments, dams and drainage system need to be reinforced, rebuilt or extended as per latest engineering standards vis-à-vis the risks.

Enhanced Financing: Despite a general scarcity of resources at the national level, allocation of sufficient funding for disaster response, management and rehabilitation is essential to avert snowballing of losses. A comprehensive assessment of requirement in this regard is paramount and is possible only with due diligence and planning.

Capacity Building: No amount of funding or infrastructure can be effective in the absence of human resource development. Training and equipping of local monitoring and response personnel is vital for the system to be effective during emergency situations. A comprehensive and realistic training regime is, therefore, essential which should include personnel of disaster management agencies, local volunteers, relevant government personnel and representatives of vulnerable communities.

Training of Communities: Awareness at local level and induction of knowhow regarding disaster response is essentially required as these communities are the fundamental stakeholders in the entire equation. Effectiveness of response and management will only be enhanced if localized education and meaningful training programs are arranged for the disaster-prone communities and their leaders.

Inclusive Communication: Remote communities have lesser access to modern education. In addition, in such communities' vernacular languages are more prevalent. It is essential that warning and training literature is translated accordingly and made accessible to respective communities.

Rehabilitation Planning: Comprehensive policies are needed to be formulated and implemented for rehabilitation of affected communities on a broader spectrum beyond mere rescue and provision of relief goods. Long term actions like housing, provision of employment and post-trauma psychological support are required.

5.2.Conclusions

The research explores the critical issue of rising floods, which are intensifying and occurring more often as a result of both urbanization and climate change. It highlights how crucial it is to use advance technology to improve the precision and promptness of flood predictions. The complexity of today's problems is beyond the reach of traditional approaches, which mostly depend on historical data and weather observations. Especially in light of floods, this highlights a serious flaw in the way we now handle disasters.

It is noted that Pakistan is a particularly susceptible country when it comes to climate-related calamities. Because of its location, widespread deforestation, and increasing urbanization, the nation is particularly vulnerable to floods. Large-scale flooding incidents like those that occurred in 2010 and 2022 act as clear reminders of our vulnerability. These floods have caused immense damage to agriculture and infrastructure, as well as the loss of many lives. Particularly severe effects from the floods in 2022 resulted in economic losses estimated to be 3% of

Pakistan's GDP. These statistics highlight the significant effects of flood catastrophes on both the human and financial fronts.

Pakistan has a difficult time incorporating contemporary techniques into its flood control plans, even with technological improvements that may be able to ease some of these difficulties. Inadequate resources, deficiencies in technical know-how, and institutional flaws impede the efficient use of current technology. The thesis highlights the shortcomings of current flood control techniques and policies, emphasizing the need for better cooperation between non-governmental and governmental organizations. Because of this lack of cohesiveness, reactions to flood occurrences have often been dispersed, which has reduced the efficacy of interventions and exacerbated the effects of catastrophes.

In order to overcome these obstacles, the study investigates the potential applications of state-of-the-art technology such as hydrological models, remote sensing, and Geographic Information Systems (GIS) for better flood risk prediction and management. These resources offer insightful information that can improve comprehension of flood patterns and support risk assessment. The thesis also looks at the revolutionary possibilities of machine learning and artificial intelligence (AI) for raising flood forecast accuracy. Pakistan can greatly minimize the damage caused by floods and expedite reaction times in times of emergency by incorporating this advance technology into its flood management systems. In addition to being advantageous, the use of these technologies is essential for creating a proactive and strong flood control plan.

In Pakistan, the National Emergency Operations Centre (NEOC) is the leader in flood hazard assessment and management. In addition to providing a thorough analysis of the NEOC's activities, the thesis emphasizes how technology is essential to increasing its effectiveness. To coordinate relief operations, give early warnings, and evaluate the effects of floods, for example, the NEOC uses data analysis. Better preparedness and speedier recovery efforts are made possible by this technology integration, which enables a more flexible and knowledgeable reaction to disasters.

The study compares regional methods to international best practices for flood control in addition to looking at local methods. The thesis highlights the need of gaining knowledge from global experiences by examining instances from nations such as Bangladesh, which utilizes community-based methods, and the Netherlands, which has an inventive initiative called "Room for the River". These parallels demonstrate how crucial it is to work together and implement proven tactics that may be modified to fit Pakistan's particular situation. Using these global best practices is encouraged by the thesis's recommendations, which also stress the need of teamwork and frameworks like the Sendai Framework for Disaster Risk Reduction.

With a particular emphasis on the NEOC in Pakistan, this study carefully examines how contemporary technology might improve flood predictions and management. It efficiently draws attention to the shortcomings of conventional flood forecasting techniques and shows how using contemporary technology is essential to enhancing resilience in the face of rising flood hazards. The study emphasizes how crucial an integrated, multifaceted strategy is for managing floods. In order to effectively handle the difficulties posed by climate change and urbanization, this strategy has to make use of cutting-edge technology, encourage international collaboration, and strengthen capability. In the end, the results of this thesis provide insightful information for decision-makers in the fields of urban planning, disaster management, and policymaking who work to strengthen flood resilience and strengthen disaster response systems in Pakistan. Stakeholders may work towards creating a more resilient future in the face of escalating environmental issues by acting decisively based on these recommendations.

5.3.Limitations

The study is substantially dependent on research primarily focused on Pakistan, particularly the National Emergency Operation Centre (NEOC), but is geographically limited. While this case study provides rich, localized insights, it restricts the generalizability of results to other regions facing similar challenges. The environmental, socio-economic, and infrastructural characteristics of different countries are varied, which may influence how the proposed solutions can be applied. Consequently, the findings might not be applicable to areas outside Pakistan, especially those with distinct political or environmental contexts.

Another limitation is the reliance on modern technologies like remote sensing, Geographic Information Systems (GIS), and machine learning. Although these are cutting-edge technologies, their accessibility in developing countries like Pakistan can be challenging due to financial constraints, inadequate infrastructure, and a lack of technical expertise. While the study highlights these technologies as essential enablers, it does not fully consider the practical difficulties in implementing such technologies in resource-poor regions.

A major challenge in the study is the reliance on data availability and quality. Many remote regions in Pakistan have inadequate data infrastructure, and flood forecasting technologies rely on real-time, high-quality data. If the data is inconsistent or incomplete, it can undermine the accuracy of predictions, and although the paper acknowledges this, it does not propose specific measures to address these challenges. The gap between ideal data requirements and the current reality is a significant limitation.

Furthermore, the study critiques traditional flood forecasting models for their dependence on historical data but fails to recognize that modern technologies also rely on vast amounts of historical data to train algorithms and validate models. In regions where such data is scarce or inaccurate, the effectiveness of machine learning and other data-intensive approaches may be compromised. The thesis does not explore how these issues could be mitigated in data-poor regions.

The study also shows a bias toward technological solutions while placing less emphasis on community participation in flood management. While it acknowledges community-based initiatives, it focuses more on technological solutions without discussing how local communities, especially in rural areas, can be integrated into flood forecasting and disaster response strategies. Given that many regions may not have access to the suggested technologies, local knowledge and community involvement are essential and should have been given more consideration.

There are also limitations arising from the institutional and policy framework in which flood management is conducted. Although the research discusses Pakistan's efforts to manage flood risks, it does not sufficiently explore the challenges related to policy implementation. Weak enforcement and lack of coordination among disaster management agencies, common in developing countries like Pakistan, often hinder the practical integration of modern technologies. This governance issue was a missed opportunity for deeper analysis.

While the thesis acknowledges climate change as a factor in increasing flood frequency and severity, it does not adequately engage with the uncertainties in climate change models. Predicting future flood events in the context of climate change is difficult due to variability in global climate models, especially when downscaled to regional levels. This unpredictability complicates the study's flood forecasting assumptions, highlighting the need for a more in-depth exploration of how to handle these uncertainties.

Although ethical considerations are mentioned, the thesis does not fully address the ethical and logistical challenges associated with using modern technologies like AI and machine learning. The collection of real-time data, particularly in disaster-prone areas, often involves surveillance technologies, raising concerns about data privacy, ownership, and equitable use. These important issues could have been explored in more detail.

Lastly, the long-term sustainability of the proposed solutions is another constraint. These systems are resource-intensive, requiring ongoing financial and technical support for maintenance and updates. Sustaining these systems in the long term could be challenging for a country like Pakistan, where resources are already stretched thin, without international collaboration and support. While the study acknowledges this, it does not delve into how these solutions could be sustained in the long run, especially in regions with limited capacity for technological investment.

While the research offers valuable insights into modern flood forecasting technologies, it has limitations including a narrow geographical focus, challenges related to data accessibility and quality, and an over-reliance on advanced technologies that may not be feasible for many regions. More emphasis on community engagement, institutional challenges, climate change uncertainties, and ethical considerations could have enhanced the relevance and applicability of the research findings.

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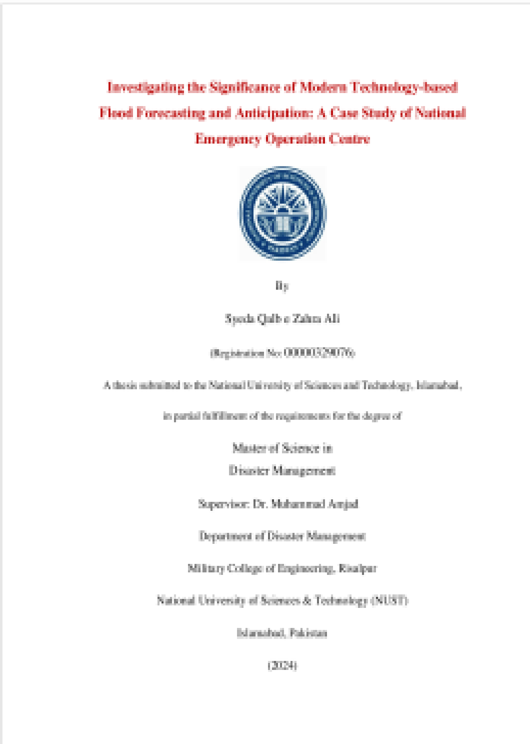

Investigating the Significance of Modern Technology-based Flood Forecasting and Anticipation: A Case Study of National Emergency Operation Centre

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