Investigation of Challenges in the Flash Flood Risk Management in the Data Scarce Regions: A Case Study of Rajanpur

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Abstract. Flash floods pose a significant threat to communities worldwide, and data-scarce regions face unique challenges in managing flash flood risks. This paper investigates the challenges in flash flood risk management in Rajanpur district, Punjab province, Pakistan. The disaster risk management cycle (including prevention, preparedness, response and recovery) is a recognized instrument for managing disaster events and their impacts. However, the usefulness of the cycle has become questionable in data scarce regions. Thus, this research uses a pragmatic approach to identify challenges in the effectiveness of the conventional disaster risk management cycle and its phases in the context of flood risk management in Rajanpur. During the analysis of risk management cycle, six key challenges have been identified: i) limited data availability, ii) inadequate early warning systems, iii) insufficient emergency response planning, iv) infrastructure design and management issues, v) poor community preparedness and awareness, vi) institutional and financial constraints. Research conclude that for of the successful run of Flood Risk Management Cycle, Primary data is compulsory which includes catchment details of torrents hitting Rajanpur along with hydro met data, details of existing infrastructure in the potential flood area, identification of safe places where community can be re-located during flood warning, Proper records of past flood events to assess the intensity of flood risk. On the basis of primary data, avoidable flood damages could be averted by the combination of non-structural and structural measures. Non-structural measures includes the preparation of flood risk zoning maps, establishing proper flood forecasting mechanism along with early warning issuance and dissemination system. Where, the structural measures may include the construction of flood protection bunds etc. The response and recovery involves the community engagement with concerned authorities as per pre-defined SOPs. Addressing these challenges requires a multi-faceted approach that includes improving data availability, enhancing early warning systems, construction of necessary flood protection structures to protect the sensitive areas, strengthening emergency response planning, and addressing infrastructure, community preparedness, and institutional and financial constraints, especially in response and recovery phase.

Keywords: Flash Flood, Risk Management, Case Study, Rajanpur.

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1. Introduction

Torrential floods are notoriously difficult to predict due to their swift nature, providing individuals with scant time to seek refuge (Mahmood et al., 2018). These types of floods primarily occur in hilly and semi-hilly regions, and can be defined as a sudden surge in the flow of river or stream water over a short period of time (Aksoy et al., 2016). Natural hazards refer to an event which affects individuals and damages property. The significance of a catastrophe is estimated financially, death toll and the ability or capacity of a nation to recover (Brooks et al., 2003). Some of these include flood, dry spell, rapidly spreading forest fires, epidemics and pandemics, earthquakes, storms etc. (Kundzewicz et al., 2015). Catastrophic events are far from the capability of people to overcome and cannot be assessed precisely. Flooding is the most common global hazard causing devastating loss (Mazzorana et al., 2014). Flooding is the common hazard and assessment of the hazard prone areas is necessary for the management of watersheds and to minimize the damages caused by the flood. Assessing floods and flood risk management is a great challenge which societies all over the globe are facing now (Aggarwal et al., 2016). It is very difficult to predict the occurrence of flash flood sites due to sudden change in climatic conditions and man-made factors. However, flood-prone areas can be pre-determined with the help of disaster forecast models and machine learning techniques to manage properly flood risks in a timely manner (Gaillard et al., 2013).

Intense severe flood events are occurring frequently across south Asia in recent years, particularly in Pakistan. Pakistan is a flood-prone country having a history of disastrous floods causing loss of lives, damage to property and infrastructure, damage to crops and land (Jonkman et al., 2008). Riverine and flash floods are the most common flood types in Pakistan. In Pakistan, flood events are historically originating from the Indus and Chenab rivers Since Pakistan's founding, the years 1955, 1959, 1973, 1976, 1988, 1992, 1995, 1996, 1997, 2006, 2010, 2014, and 2020 have been marked by severe floods that had a negative impact on property, human lives, and the nation's economy (Ibarra et al., 2007).

The consequences of flooding are devastating, with numerous fatalities and injuries often occurring in close proximity to stream beds and Nullahs. Globally, flooding affects an estimated 140 million people, while approximately 196 million individuals across 90 countries are impacted by its aftermath (WHO, 2003; UNDP, 2004). For example between 1995 and 2015, a staggering 2.3 billion people were severely affected by floods, accounting for a staggering 47% of all climate-related disasters worldwide (UNISDR, 2015). The underlying causes of flooding are interconnected. Rising temperatures, polar thaw, and thermal ocean amplification lead to increased rainfall, resulting in a rise in sea levels and consequent flooding of coastal regions. Other factors contributing to flooding include excessive rainfall in river basins, ice jams, melting snowpack, and land-use changes such as urbanization and deforestation. Pakistan ranks among the top 10 countries worldwide most affected by climate change. The country has observed changing weather patterns, including variations in precipitation and temperatures (Un-Habitat et al., 2012).

Floods in Pakistan are mainly caused by heavy rains and melting glaciers in the upper Himalayan region during the monsoon season in July and September 2022. The unpredictable extreme weather events have been putting the disaster risk management in a challenging situation (Jha et al., 2018). Floods in 2010 have been reported worst affecting several areas in the provinces, G-B, FATA and AJ&K. This disastrous event caused around 1985 deaths, damaged 1608184 houses, destroyed 17553 villages and affected a total area of 160000 km2. National Disaster Management Authority Pakistan (NDMA-2018). Pakistan experienced five consecutive torrential flash flood events from 2010 to 2015. In September 2012, heavy monsoon rains caused havoc in urban and adjacent rural areas of D.G. Khan. Punjab was affected by these flood events; these events mainly affected the districts of Dera Ghazi Khan, Rajanpur, Muzaffargarh and Rahim Yar Khan (Ali et. al., 2019). In the summer of 2022, record-breaking rainfall brought an unprecedented humanitarian crisis to the country. Over June–August 2022, Pakistan received nearly 190 % more rain than its 30-year average. The heavy rainfall caused widespread flooding, which was exacerbated when the Indus River, which runs the length of the country – burst its banks (El-Gamily et al., 2010). The month of august the received rainfall is 358.9 mm against normal average of 116.8 mm with a huge difference of 207 mm rainfall. (PMDA-2022).

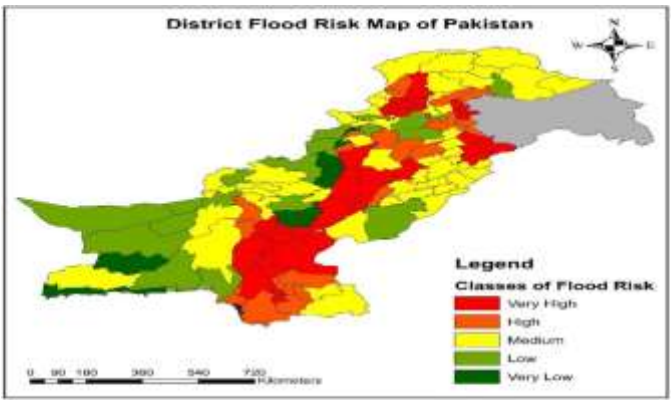

Figure 1: Disaster Flood Risk Map of Pakistan.
***National disaster Management Authority**

The patterns of Floods in Pakistan are quite systematic, which is classified as per the location of Rivers and Mountains. Refer to Fig-1, District wise Flood risk in Pakistan is shown, in which Bright Red color indicate the very high Risk zones District. In Punjab District Rajanpur lies in High Risk due to Mountain of Koh-e Suleiman on the west and Mighty Indus River on the East.

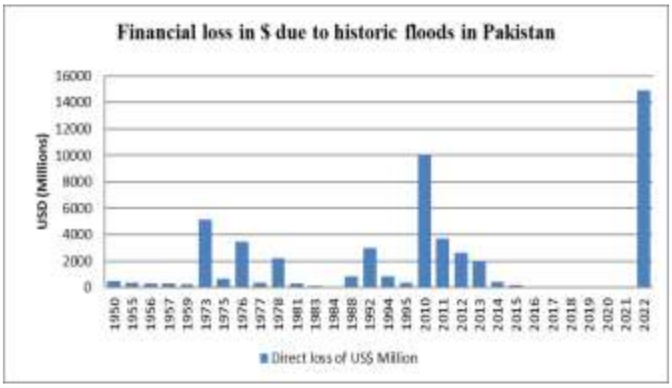

Figure 1: Historical Floods with Damages in Pakistan.
*** (Source: Economic Survey of Pakistan, 2011-12)**

Pakistan is one of the most affected countries by climate change. As indicated in Fig-2, the direct loss to economy due to 2010 flood goes up to 10 Billion US$, similarly a recent flood-2022 cost more than 14 billion$ direct loss to the national economy.

With reference to Fig-3, on average 6000 villages per annum are affected due to floods in Pakistan. Some of the historic floods like1976 damaged more than 18000 villages. In 2010 floods 16500 villages were affected, similarly in recent flood-2022, 18200 villages were affected.

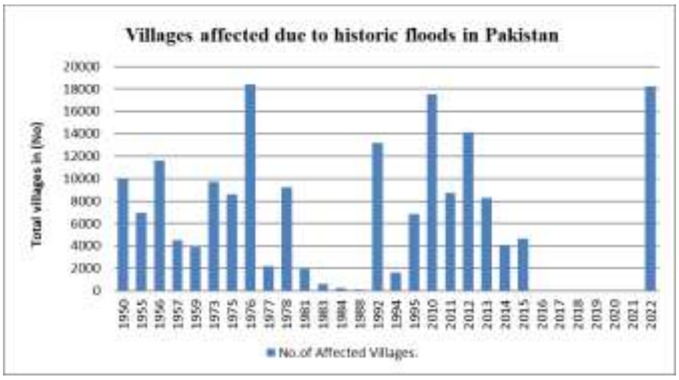

Figure 3: Villages affected by the floods in Pakistan.
*** Economic Survey of Pakistan 2011-12**
**** NDMA-2022**

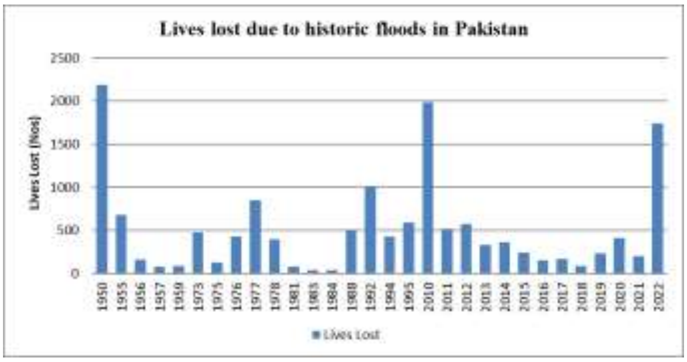

Figure 4: Lives losses due to historic floods in Pakistan.
*** Economic Survey of Pakistan 2011-12**
**** NDMA**

From 1950 to 2022 more than 15000 people lost their lives due to these historic deadly floods in Pakistan, Refer to Fig-3, death toll is high in 1950 which is more than 2000 in a single year, similarly in 2010 more than 1900 people lost their lives, and now in recent floods Pakistan has lost almost 1800 people to flood. On average almost 400 people died every year due to these deadly floods.

Rajanpur is the Southern-most district of Punjab Province. Rajanpur District lies in the southwest of the Punjab Province at 29°06' N latitude and 70°19' E longitude. Rajanpur district is situated in the west Indus River and it is a narrow 32 km to 64 km wide strip of land sandwiched between Indus River and Suleiman mountains. It has three tehsils and all tehsils were exposed to flood water. Its population comprises of 2,872,63 (Censes 2017).Being close to the river bed, the eastern part of the district is frequently hit by flooding from the Indus River due to heavy monsoon rains in July/August. This riverine flooding inundates a large part of the low lying areas along the river belt in all three Tehsils (sub-divisions), namely Jampur, Rajanpur and Rojhan as indicated in Fig-5, highlighted in different color. The western part of the district is frequently affected by "Flash / Torrential Floods" which develop in the Suleiman mountain ranges. Both these flood hazards (Riverine & Torrential) bring heavy losses in the areas adjacent to main river and torrents that cover roughly about 80% of the total area and about 60% of the population, damaging houses made of mud, land and crops, livestock and other property (District Disaster management Plan DDMP, 2022). The lands in the Western area are relatively steep and this tends to facilitate flash- flooding due to torrential rains in the Suleiman range in July/August (or in some cases February/ March). Flash torrential floods on the western side are considered more serious than the riverine floods for the communities. In case of the frequent severe flash floods, communities face heavy losses of standing crops, livestock, houses which are usually made of mud, and other physical infrastructure. The climate of the district is tremendously hot in summer while in winter it is very cold due to nearness to Koh Suleiman range of mountains.

More than 200 Hill Torrents emerge from Suleiman Mountainous Range and mostly flow southeast, out of which 13 are major torrents (7 in D.G. Khan District and 6 in Rajanpur District). It inundates vast area of Districts D.G. Khan and Rajanpur. The Hill Torrents are a regular feature and bring devastation, off and on in the two districts. These Torrents caused flooding and vast devastation in the years 2010, 2012, 2013, 2015 and 2022. Due to intermittent spell of heavy raining during monsoon season i.e. July to September, the western part of the district is frequently affected by the flash floods generated monsoon and localized cloud burst originating in the Suleiman Ranges. Therefore, both the eastern and western side receive flooding due to riverine flood and torrential flash floods respectively causing heavy damages, effecting approximately 80% population of eastern side and 60% of western side beside damaging Katcha houses, lands, crops, livestock and properties. Monsoon rains normally starts from June-July with torrential rains giving rise to heavy flash floods in the Suleiman Range affected areas with maximum discharge of up to one lac cusecs (Federal Flood Commission, 2022)

The geological features of Rajanpur Hill Torrents are conglomeratic sandstone, moderately hard, associated with weak siltstone beds. The sandstone beds are inter-bedded with clay stone/siltstone beds these rocks have similar dip direction and the angle. The sedimentary rocks consisting sandstone and limestone located at middle to northern parts of District Rajanpur.

Agriculture is the primary industry in Rajanpur District. In the District of Rajanpur, almost 60% of the people survive mostly off agriculture. The production of agriculture is particularly fragile due to its geographic position and climate.

Rajanpur has faced major floods in the past; in 2010 Riverine flood damaged a lot, similarly on the western side of Rajanpur the Koh-e-Suleiman mountain range gave rise to a flash flood risk. In 2020, flood water affected more than two million residents of rajanpur. Most damages reported due to floods in rajanpur in year 2006, 2010,2012,2015,2020 and 2022 having a significant no. of mortalities, crop distraction and Animal Perished. Provincial Disaster Management Authority (PDMA Annual report 2022).

Refer to Fig-6, Red color mentioned district are notified calamity hit district, Rajanpur is one of the most vulnerable in term of flood risk because it is surrounded by Mountains in the West, which brings torrential flash floods and River Indus on the east cause riverine flood. Brown area in Fig-6 also depicts the medium vulnerable districts in term of Flood Risks.

The purpose of this study is to identify the challenges involve in developing effective flood risk management system in the study area i.e. Rajanpur District's to mitigate the harmful effects of floods. This study provides an invaluable contribution to identify the best model for flood risk management in data-scarce regions like Rajanpur district that is located at the outlet of hill torrents of data-scarce catchment of Koh-e-Suleiman.

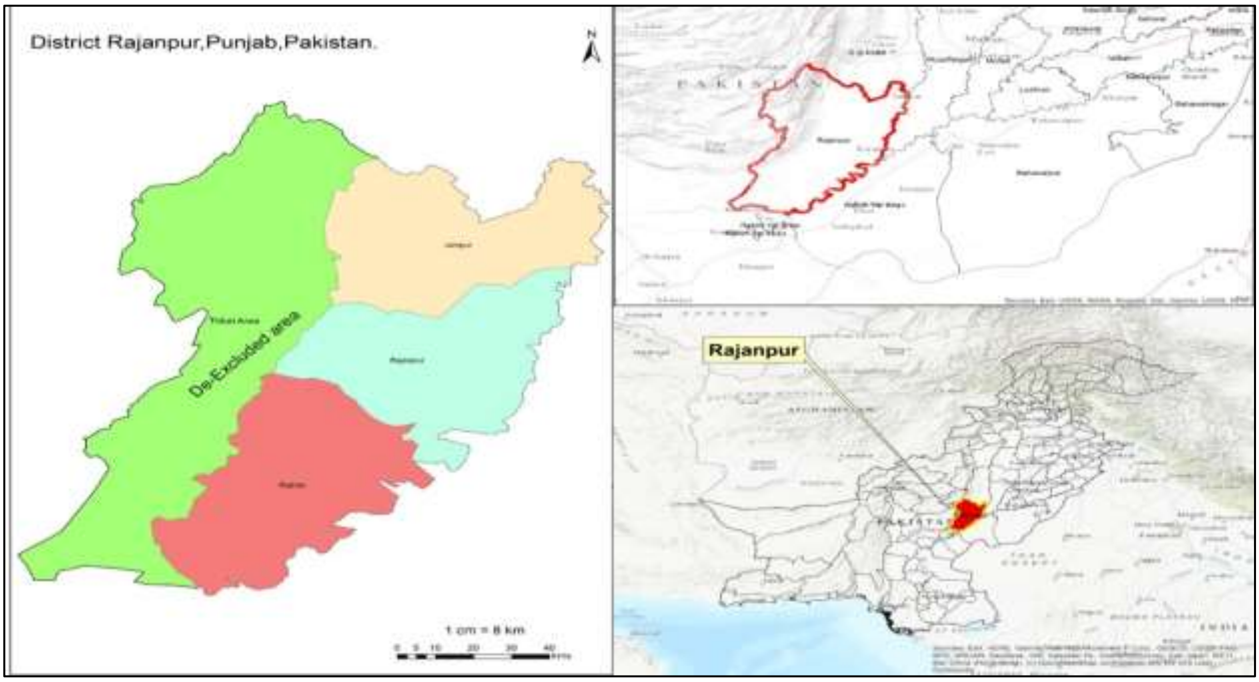

Figure 2: Map of Study Area (District Rajanpur)

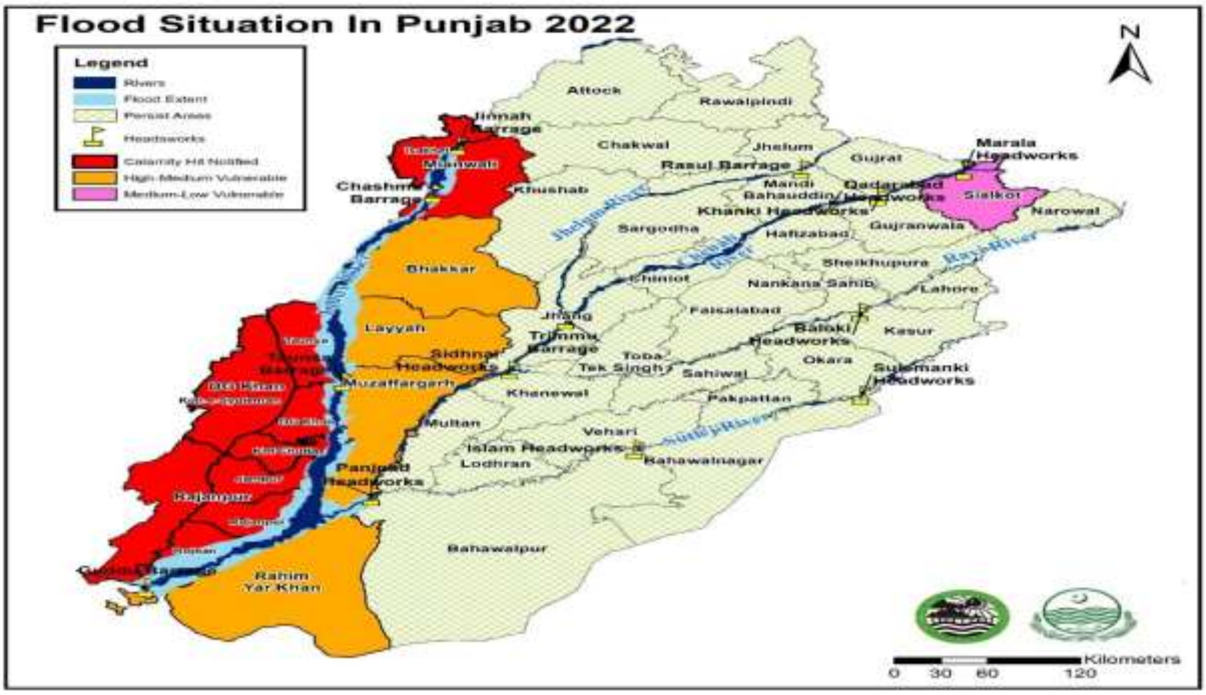

Figure 3: Flood situation map of Punjab.
***Provincial Disaster Management Authority**

2. Literature Review

Development of Flood Risk Management (FRM) including different methods and models largely depends upon the nature, type and intensity of flood as well as type of gauging and data availability. There are many approaches dealing with FRM with respect to Structural and non-structural measures. Some of the result oriented models which are being used with different parameters are discussed by (Grabowski et al., 2019). The goal of natural flood management (NFM), which is gaining popularity as a flood risk management strategy (Grabowski et al., 2019), is to restore natural hydrological and geomorphological processes in order to slow and store floodwater in the landscape (Forbes et al., 2015). In addition to flood risk reduction, NFM strategies offer other advantages. These strategies include afforestation and soil management techniques.

Nature-based solutions (NBS) can act as a valuable complement to conventional 'grey' infrastructure for storm water management (e.g. dams and dikes) in reducing flood risks as these 'green' solutions are perceived to be more flexible and multifunctional. However, to achieve effective NBS, a multi-actor approach in developing appropriate measures for specific sites is required as NBS occupy more space than 'grey' infrastructure and often overlap with private land. NBS as a boundary concept, focusing on the common ground for different disciplines and actors, can facilitate communication and provide a first step towards effective flood risk mitigation (L.M. Soanes et al., 2023).

In regional flood frequency distribution and parameter estimation method, the two steps in the index flood method are, in modified versions, common to all regional flood estimation procedures. The first part of the analysis is to identify sites which seem sufficiently similar to the target site to provide a basis for information transfer. In practice, one can employ different similarity measures and classification techniques. In the following, these are referred to as DHR (determination of homogeneous regions techniques). The second part of the analysis is to perform the information transfer, i.e. to actually infer flood quintiles at the target site using data from the sites identified in the first part of the analysis. The assessment of relative performance of various regional flood frequency procedures by a systematic comparison of possible combinations of DHR and REM was reported by (Benson et al., 1962; Wiltshire, 1986a, b; Cunnane, 1989; Cavadias, 1990).

The temporal flood risk arises from the vulnerability and hazard indicators of the urban system. Spatial analysis of selected flood events was conducted and the impact of LULC change on the Flood Risk in the present analysis was also examined by (Yamazaki et al., 2014). Whereas, the integrated flood management approach includes development and enforcement of a comprehensive legal framework, effective floodplain zoning along with its enforcement, land use planning, improved forest laws and their effective enforcement and preservation of wetlands. Forestation, wetlands preservation and Land use planning is a major tool for reducing risks from floods and contributes towards sustainability and enhanced resilience. Risk-based planning provides an opportunity to move beyond planning for a natural hazard (Morelli et al., 2021).

In the absence of sufficient historical data, modeling techniques based on the hydrodynamic approach are rapidly gaining preference for flood simulation. RRI (Rainfall-Runoff-Inundation) model is a conventional approaches used for modeling regional flooding, which is primarily caused by the surrounding watersheds, provide independent or integrated simulations of the catchment hydrological and hydraulic processes. However, the model requires topography (static) and rainfall (dynamic) data as inputs. This study uses the topography data developed by generating an enhanced DEM by combining different types of data from various sources (Anselmo et al., 1996).

In cases where no at-site data are available for flood assessment, one may use data from gauged neighboring catchments, or, in general, data from catchments with similar hydrologic regimes. The index flood method, proposed by (Dalrymple et al., 1960), was one of the first approaches to regional flood estimation. This method consists of:

• The identification of geographically homogeneous regions;

• The determination of a regional standardized flood frequency curve.

As a matter of fact, there are some serious problems of developing flood risk management system in the data scarce region as remotely sensed data is most often not validated by ground situation. Yu Chen et al., (2015), study selected eleven flood hazard conditioning factors as evaluation criteria to obtain GIS maps with three multi-criteria analysis (MCA) techniques i.e., 1) Analytical hierarchy process (AHP), 2) technique ordered preference by similarity to the ideal solution (TOPSIS), and 3) ordered weighted averaging (OWA), to form a GIS-MCA framework for analyzing the spatial distribution of flood-prone areas. Its application in the Dadu River basin, China derived a total of eleven flood hazard maps across the basin, and their analysis and comparison results demonstrated the spatial distributions of flood-prone areas based on various GIS-MCA approaches.

As per (Alimiet et al., 2015), flood risk mapping was necessary because of the constant flooding. The goal of this research was to use geospatial techniques to map out the regions of Osogbo Metropolis that are susceptible to flooding in order to aid in appropriate planning and provide long-term solutions to the damage that flooding frequently does to people and their properties in the metropolis. The flood-vulnerability zones identified by this study may direct relevant policymakers in their deliberations towards averting flood catastrophes (Ibarra et al., 2012).

The study can help integrate the philosophies of disaster risk reduction and climate change adaptation. Flooded area was calculated using a variety of water indices (Water indices are often based on surface reflectance in the range from visible bands to short-wave infrared bands) and calculated on Landsat data. Pre-flood, during flood, and post-flood satellite data were collected for in depth food investigation. The delineation of inundated areas was done using the Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), and Water Ratio Index (WRI). In order to detect and compare flooded areas with water indices, the supervised maximum likelihood algorithm was also used for land use and land cover mapping.

Various studies have been conducted to develop the flood risk management model and to evaluate the Damages due to flash torrential and riverine floods in Northern Areas of Pakistan. But In District Rajanpur South Punjab almost every year flash flood factors affecting the infrastructure and human living. Until today only preliminary Studies of different hill Torrents are conducted which are to be further investigated for developing effective flood risk management system. Never the less, several researchers have conducted studies to utilize the torrential flood for agriculture purpose but still there is a research gap regarding forecast of flood volume, magnitude and time of its peak flood occurrence to mitigate the harmful impact of foods. The challenges of suggesting a suitable model for flood risk management; identification of flood vulnerable zones with the help of remote sensed-based approach requires further investigation. Furthermore, a research on flood frequency and the designated flash torrential flood dangerous zones in District Rajanpur is still lacking, making it difficult to for flood risk reduction using non-structural methods. Therefore, the current study is designed to explore the challenges involved in developing effective flood risk management system to mitigate risk cause by deadly hill torrents that hit Rajanpur district.

3. Methodology

Since, Koh-e-sulaiman catchment, housing the hill torrents that cause flooding in Rajanpur district, is a data scarce region due to hilly terrain and lack of resources. Where, around 200 hill torrents emerged from this mighty mountain range. Moreover, flood Risk management is very challenging and tricky due to increasing flood frequency possibly due to climatic changes. To mitigate or minimize flood destruction both Structural and non-structural measures are required for running flood risk management cycle. In developing flood risk reduction strategies, both the qualitative and quantitative levels of flood forecasting and flood risk examination are crucial. The inventory of elements at risk as well as statistics on hazards, exposure, and vulnerability are used to calculate the flood risk in the study area. In the conduction of this study, the literature concerning flood risk management is reviewed for possible application in the study area. The past research concerning flood risk reduction in the study area is further reviewed to identify the bottlenecks in developing effective flood risk management system to minimize the avoidable flood damages in the Rajanpur district. To start with, the quality and quantity of data required to develop effective flood forecasting model and risk zone maps is analyzed. The availability of data quantity and quality pertaining to the following is considered: 1) Catchment boundaries of the hill torrents hitting the study area 2) Rainfall and discharge data, 3) land use and land cover (LULC), 4) topographic data including DTMs and DEMS, 5) stream proximity (SP), 6) Topographic Wetness Index (TWI), 7) drainage density (DD), 8) normalized difference vegetation index (NDVI), 9) Previous flood effecters and history/damage report, In the next step, the situation of previous non-structural and structural measures to minimize the flood risk are analyzed. . Moreover, the effectiveness of risk communication mechanism to the stakeholders is studied followed by the conditions of rescue and relief measures. The challenges involved in the flood risk management in Rajanpur are analyzed in a manner that the solution could be suggested for developing holistic flood risk management system.

Water can seep through permeable concrete, causing leaks. This may result in water loss, lowering the tank's capacity and possibly causing nearby regions to become moist or flooded. Dashtibadafridi et al., (2017) stated that concrete become weakened by water seepage. Since, water has the ability to dissolve minerals and release calcium hydroxide, which is essential to the strength of concrete, as it permeates. This may cause the tank's structural integrity to be compromised and result in cracking and flaking.

Corrosion may result from water seeping through the concrete and reaching the steel reinforcement bars inside. This may lead to structural failure by weakening the reinforcement. There low permeability concrete should be preferred for water tanks. According to Dashtibadfarid et al., (2017) Low-Permeability Concrete reduces water seepage and guarantees the tank retains water efficiently. Where, the building water tanks that waterproof requires an in depth understanding of the concrete permeability.

Numerous studies in this field have shown that industrial wastes can function as efficient substitutes for conventional cementitious materials. The permeability and water absorption of the mortar are affected by the addition of industrial ashes. Since, these industrial by-products have pozzolanic qualities, therefore, they can improve the final cement paste's quality and enable to give fruitful results according to requirement, which can save money and energy (Dixit et al., 2020). This study's primary goal is to investigate the impermeability of mortar cubes in water while taking various ash kinds into account.

4. Results and Discussions

4.1 Challenges involved in FRM of District Rajanpur due to data scarcity

The analysis revealed that limited data availability, inadequate early warning systems, insufficient emergency response planning, issues in infrastructure design and management, poor community preparedness and awareness, and institutional and financial constraints are the major challenges in flash flood risk management in Rajanpur district. The details with respect to District rajanpur is given as under;

Data Availability Constraints: There are notice-able hill torrents that emerge from the Koh-eSulieman mountain rnage and hit Rajanpur. Where, the catchment areas of 12 main Hill torrents are given in Table-1. Among these 12, Sanghar, Vehova and Sori Janubi are having the catchment area of 2720, 4880 and 1680 Square-Km respectively.

In order to develop a Flood Risk Management (FRM) model for Rajanpur District, the primary data includes Rainfall data, Discharge data, Catchment Details, Previous flood history to follow flood pattern and Flood damages report from the field is essentially required. Similarly, the secondary data includes Land use Land cover, Vegetation index, Digital Elevation Models, Digital Terrain Models, Soil type etc.

Table 1: Catchment Areas of Hill Torrents.

Catchment Areas of Hill Torrents		
Sr. No.	**Hill Torrent**	**Catchment Area (km^2)**
1	Kaura	450
2	Vehowa	2,720
3	Sanghar	4,880
4	Sori Lund	520
5	Vidore	770
6	Sakhi Sarwar	160
7	Mithawan	680
8	Chachar	800
9	Pitok	240
10	Sori Shumali	330
11	Zangi	400
12	Sori Janubi	1,680

***Punjab Irrigation Department (PID)**

**** Water and Power Authority (WAPDA)**

Rainfall data: One of the most import challenge while developing a Flood risk management cycle is data acquisition and the quantity and quality of available data. Both the flood forecasting models and flood risk zoning requires the rainfall, discharges and water level data. As far as rain data of Rajanpur district is concern, there is neither any rain gauging station in the Rajanpur district nor in any catchment of any torrent that brings floods to Rajanpur. Rainfall data of nearby station Barkhan is collected that is almost 100 km Away. The station is operated and maintained by Pakistan Meteorological Department (PMD). Daily rainfall data for the period of 1911-2020 is available for the Barkhan rain gauging stations that is given in Table 2. Table 1 & 2 shows Annual Max Rainfall data from Barkhan Station which is almost 200 Km Away from the Rajanpur As can be seen in the table-1 that the variability of inter-annual rainfall is high; annual rainfall of Barkhan is 16.5 inches while minimum and maximum recorded annual rainfall magnitudes is 3.86 inches and 29.53 inches respectively (1911-2020).

Since, only one station, Barkhan, in the neighbor-hood is having long term record, therefore, to generate long-term rainfall series of varioushill torrents in Rajanpur, Barkhan’s daily rainfall data for the period (1911-2020) could be used. However, the annual normal map suggests that average annual rainfall in the catchments of Rajanpur Hill torrent is 301 mm (11.85 in). Therefore, direct application of Barkhan rainfall to the Chachar (one of the torrent hitting Rajanpur) catchment may not be justified as the elevation of Barkhan is higher than the average basin height. Unless, a proper study is conducted, the data of Barkhan station could not be used in the catchments of any hill torrent hitting Rajanpur.

Table 2: Annual Maximum Rainfall at Barkhan Station.

Annual Maximum Rainfall at Barkhan Station							
Year	Annual Max. Rainfall (inches)	Year	Annual Max. Rainfall (inches)	Year	Annual Max. Rainfall (inches)	Year	Annual Max. Rainfall (inches)
1911	10.79	1933	10.91	1977	17.68	1999	13.03
1912	14.49	1934	10.91	1978	23.07	2000	5.75
1913	22.91	1935	10.12	1979	22.60	2001	12.80
1914	20.51	1936	12.60	1980	15.35	2002	3.86
1915	9.80	1937	15.31	1981	12.99	2003	13.86
1916	14.49	1938	30.63	1982	20.47	2004	11.34
1917	26.42	1939	6.30	1983	18.78	2005	19.84

1918	13.39	1940	8.82	1984	23.78	2006	29.53
1919	11.61	1963	10.98	1985	13.23	2007	14.72
1920	18.39	1964	11.38	1986	9.61	2008	10.91
1921	13.70	1965	17.40	1987	12.13	2009	10.31
1922	18.58	1966	12.72	1988	5.47	2010	18.50
1923	18.39	1967	27.13	1989	19.57	2011	17.52
1924	10.20	1968	22.05	1990	19.06	2012	14.45
1925	10.51	1969	8.54	1991	12.28	2013	15.91
1926	14.09	1970	4.29	1992	23.82	2014	19.72
1927	5.12	1971	10.63	1993	20.20	2015	14.33
1928	8.31	1972	20.79	1994	23.54	2016	17.72
1929	10.91	1973	15.00	1995	18.19	2017	14.09
1930	10.91	1974	12.80	1996	15.98	2018	9.65
1931	10.12	1975	7.48	1997	29.13	2019	19.64
1932	12.60	1976	12.24	1998	11.81	2020	18.11

***Pakistan Meteorological department.**

Discharge Data: All the previous studies in the region mainly relies on annual maximum discharges given by Punjab irrigation Department (PID). Where, PID has no historic long term record prior to 2003 of various gages. Recently collected data has also some missing data .Where, data recorded at tar room (communication center working under PID) communicated for flood warning and to concerned offices of hill torrents may have similarity issues in dates and magnitudes.

Table 3: Annual Instantaneous Peak Discharge at Chachar Hill Torrent

Annual Instantaneous Peak Discharges at Chachar Darrah			
Year	**Annual Instantaneous. Peak Discharges (ft^3/s)**	**Year**	**Annual Instantaneous. Peak Discharges (ft^3/s)**
1958	5,706	1985	16,600
1959	56,500	1986	32,847
1960	43,417	1987	1,413
1961	37,212	1988	29,669
1962	64,187	1989	31,435
1963	26,447	1990	36,528
1964	11,779	1991	29,750
1966	53,000	1992	28,413
1967	52,989	1993	23,926
1968	50,000	1994	61,500
1969	45,000	2003	37,000
1970	40,000	2004	2,976
1971	38,000	2005	6,743
1972	27,000	2006	0
1973	34,000	2007	17,100
1974	31,000	2008	28,000
1975	10,650	2009	14,300
1976	12,000	2010	30,000
1977	12,650	2011	16,000
1978	45,000	2012	49,500
1979	7,512	2013	65,000
1980	5,192	2014	2,250
1981	5,192	2015	24,300
1982	9,748	2016	24,300
1983	72,618	2017	5,250
1984	10,667		

***Punjab Irrigation Department.**

Table-3 indicates the Annual Instantaneous Peak Discharges at Chachar Darrah. The Minimum Peak discharge is 2250 cusecs while Maximum Peak instantaneous discharge is 65000 ft3/s. There are almost 200 Till torrents in total emerging from Koh-e-Suleiman and their annual Discharge is the root cause of flash flooding in the region. Mainly, there are around than 40 hill torrents / Nullahs (06 major + 34 minor) emerges from Koh e suleman that destroy and damage residential or compact populated areas of Rajanpur. Where, discharge data is available for only two Hill Torrent, i.e. Kaha and Chachar. Where, the data of Chachar Darrah is available from 1958 and onwards.

Geological and Geographical constraints: Suleiman Mountains range is quite vast starting from KPK province and entered in Punjab, forming a border between KPK and Punjab at some places. District Rajanpur is geographically very special having Suleiman mountain range on western side and Mighty Indus River on the East. Due to mountainous terrain, it is very difficult to Geo tag each of Nullahs and due to non-availability of Rainfall discharge gauges in the catchments of many torrents, prediction of intensity and direction of flash flood is very difficult. Similarly, no proper research has made in term of collecting complete geological information of koh e Suleiman. Geological data is available at some points of Kaha and Chachar hill torrent where dam was proposed in the past. The generalization of that geological data to whole Sulieman mountain range may not be justified without proper validation through further investigations. Remotely sensed data could be used to delineate catchment, preparing DEMS, DTMs and acquiring top soil, land surface and land cover, however, ground validation would be required especially for sub-surface geological data.

4.2 Non-Structural Measures to Mitigate Negative Impacts of Flood

Inadequate mapping and flood risk zoning: The available maps of Koh-e-Sulaiman region are inadequate and have incomplete topographic, hydrographic, geologic, soil cover, land cover and land-use details of the catchments of various hill torrents that cause flooding in the Rajanpur district. LULC, wetness index, Slope and elevation maps are not validated by the ground based observations.

In the absence of proper physiographic data, the choice of flood forecasting model became limited to simple conceptual models, lumped or black box models provided sufficient record of hydmet. data is available. Furthermore, the available maps of Rajanpur are outdated with respect to vital infrastructure details, land settlements, towns, health care facilities, educational institutes, vulnerable communities which poses a serious drawback to have proper geospatial information necessary to develop FRM model.

Furthermore, flood risk zonation with reasonable confidence interval is another issue to be tackled with. Therefore, preparation of probabilistic flood risk zoning maps with careful analysis regarding their validity in the wake of climate change is to taken into account for effective prevention and the preparedness for the flash floods. Various studies have predicted that climate change would aggravate floods in Pakistan due to high glacial melting and deicing of mountain caps and high monsoon rainfall. The frequency of floods in Rajanpur has substantially increased due to changing rainfall patterns may be due to climate change in the recent years. So the intensifying impacts of climate change on flooding demands for a holistic, proactive and integrated approach for effective flood management.

In Fig-7, Flood extent map shows flooded area of Rajanpur district. All three tehsil, Jampur, Rajanpur and Rojhan including Tribal Areas was under destruction of deadly flood occurring in 2022. However, the preparation flood risk maps require extensive hydrologic and hydro-dynamic modeling for transformation of rainfall to runoff and for runoff routing upto the Rajanpur district, in prior.

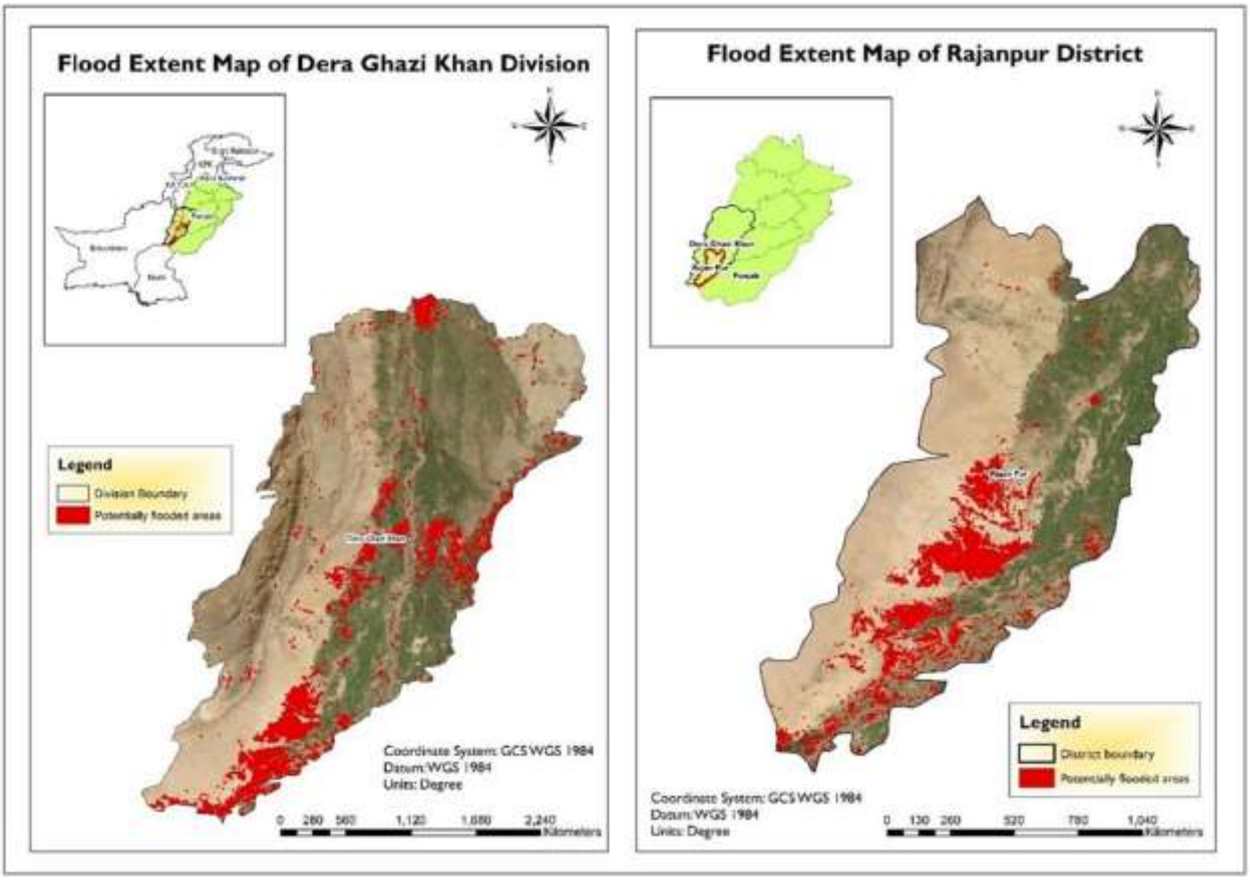

Figure 07: Flood-2022, extend Map of Rajanpur

In-Actionable Flood Forecasting: Pakistan Meteorological Department normally issues the forecast regarding floods in the country. However, its main focus remains on the riverine flooding. Nevertheless, it issues the rainfall storm warning with the chances of flooding in the torrential flood prone areas. But its forecasting is short of discharge volume, water levels, flood peak and time of flood peak occurrence and with limited lead time. Therefore, the communication of rainfall forecast, in the absence of necessary data which forms an actionable information for the communities and the authorities to take decision regarding vacating the potential flood areas in time, strictly hamper the effectiveness of flood forecast.

Lack of Comprehensive Policy for Flood Risk Management: Currently, Pakistan does not have approved national water and flood policy. Pakistan's draft flood policy seems to consist of a plan rather than a policy. Also, Pakistan's current draft flood policy does not consider flash flood which is very unfortunate. Federal Flood Commission Pakistan (Annual Report-2008).

Lack of Effective Flood Preparedness, Fighting and Post-Flood Operations: Currently, Pakistan lacks in integrated and effective flood risk management mechanism. In Rajanpur, lack of efficient flood preparedness policies, strategies and actions aggravate the flood situation. The current flood fighting plans lack in integrated and holistic flood management strategy involving all the stakeholders in coherent manner for integrated action. Pakistan also lacks in effective post-flood management activities including relief and sustained recovery possibly due to poor institutional coordination and weaker accountability checks. The post-flood rehabilitation task is a major challenge. The rebuilding of the entire infrastructure including the irrigation channels, communication systems, roads, bridges, schools, and hospitals, in addition to accommodation of displaced people along with provision of food, water and sanitation facilities is a big and difficult task across the country. This entire process needs comprehensive policy and planning measures (including short, medium and long term plans) which are currently largely missing in Pakistan in general and in Rajanpur in particular.

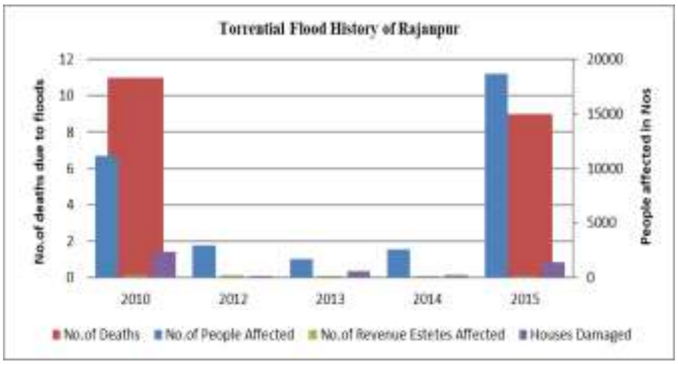

Figure 8: Torrential Flood History of Rajanpur.
***Federal Flood Commission (FFC)**
**** PDMA-(Annual Report -2022**

Rajanpur due to its Tricky geography of having Suleiman Mountains on Western side often faces Torrential flash floods. In 2010 flash flood in rajanpur has damaged more than 2300 houses, and affected more than 10000 people with 11 life losses. 2015 flood was also very disturbing as 9 people lost their life and more than 15000 people were affected.

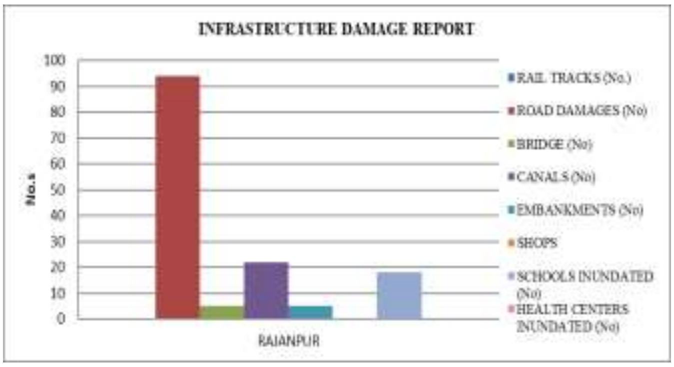

Figure 9: Infrastructure damage Report for Rajanpur flood-2022
***Federal Flood Commission (FFC)**
**** PDMA-2022**

On ground collected infrastructure damage data due to torrential flash flood as mentioned in fig-8, shows 94 no of roads, 22 canals and 18 School inundated.

Rajanpur district is very backward in term of infrastructure and standard of living, mostly people living in rural areas in Kucha Houses made with mud and bamboos having no proper reinforcement. As per Fig-09, 35000 houses were affected including 12000 houses completely destroyed.

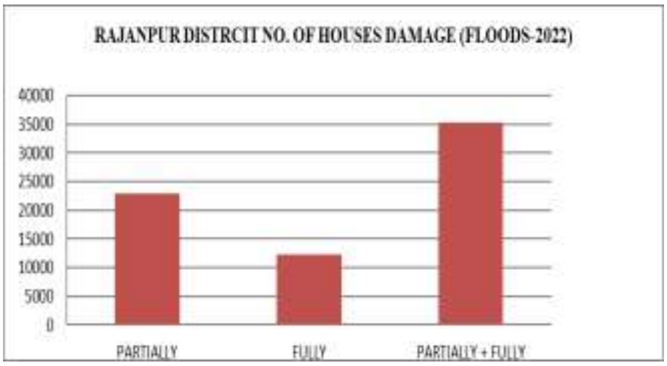

Figure 10: House damages data Rajanpur district (Flood-2022).
***District Government Rajanpur.**
**** PDMA-2022**

As per UN guidelines a reliable Flood Risk management contains authentic data of study area up to 25 years for the adoption of any flood Risk management is compulsory, while considering the data availability situation in Rajanpur , it requires significant improvement. As per table 4: Deadly torrential flood affected more than 250.000 people, with 13 lives lost. 35,000 houses damaged and almost 350,000 acres crops affected. Hence this research to evaluate the challenges in the flash flood risk management is vibrant approach to overcome such deadly floods.

Lack of Community-Based Flood Management Program: Community-based efforts contribute significantly towards effective and sustainable flood control. Community participation is vital in relief, recovery, and reconstruction phases. Currently, District Rajanpur lacks in effective community participation in flood management.

Table 4: Flood damage data-2022

Sr.	Losses / Damages & Rescue / Relief		Tehsil Jampur	Tehsil Rajanpur	Tehsil Rojhan	Tribal Area	Total
1	Union Council Affected		*24*	11	*12*	-	*47*
2	Mauza Affected		113	112	*88*	*43*	*356*
3	Area Affected (acres)		337,545	180375	*252,937*	-	*770,857*
4	Crop Area Affected (acres)		218,889	91733	*40,278*	-	*350,900*
5	House Damaged	Kacha	17,822	13,173	4,295	-	35,290
		Pacca				-	
6	Population Affected		69,484	132,886	*50,930*	-	*253,300*
7	Persons Injured		*747*	1,345	*1,085*	-	*3,177*
8	Deaths		4	8	*1*	-	*13*
9	Animal Perished		*109*	*37*	*53*	-	*199*
10	Relief Cut + Road Cuts		*111*	*14*	*36*	-	*161*
11	Schools Affected		-	*18*	-	-	*18*
12	Health Centers Affected		6	*7*	*3*	-	*16*

***Provincial Disaster Management Authority (PDMA-2022)**
****District Government Rajnapur.**

4.2 Structural Measures to Mitigate Negative Impacts of Flood

Existing Flood Protection Measures: As per Federal Flood commission and national Disaster Management Authority some union councils of Rajanpur district are facing torrential flash flood almost every year from past 50 years. Punjab irrigation department in 1958 and 1977 had constructed flood protection embankments and spurs in tribal area but with the passage of time with no maintenance, these structures are now destroyed due to repeatedly flood events.

Where, in late 90s irrigation department constructed more spurs, embankments and diversion structures to regulate flood and to provide a safe exit from populated area to Indus River. But with the passage of time these structures were badly affected by flash flood and now there existence is not serving the purpose resulting flash flood routes are hitting the dense populated areas. In some cases, the population spread to the banks of existing routes of old torrents, especially those which remained calm for decades. The oldest structures are in poor condition due to lack of adequate maintenance. In Rajanpur, main issues related to flood infrastructure include improper planning, design and implementation of flood protection infrastructure, partial implementation of flood works due to delay in approval, funding and construction and poor maintenance due to inadequate funds. Where, the construction of sustainable infrastructure for protection of settled area from the floods requires detail research to determine accurate estimate of floods, especially flood peaks of different return periods at each major hill torrents.

4.3 Availability of Resources for Flood Risk Management

Pakistan suffered cumulative flood damage of US$38.165 billion from 1947-2021 and invested PKR 29.35 billion (US$279.524 million at the 2021 rate; 1 US$ = PKR 105 (old conversion rate)) (Bureau of statistics Pakistan-2010), to mitigate the floods effects during this period. This Investment was made on implementation of 5410 flood projects. However, a larger part of investment was spent on relief and recovery by transferring financial resources to the flood victims from public funds. This reflects a Reactive approach to flood management, where the holistic pro-active approach to maximize the flood benefits and minimizing the flood damages is largely missing.

4.4 Holistic Approach for Flood Risk Management

Proper flood risk management cycle requires careful holistic planning to categorize floods and setting action plan to maximize the benefits and minimize the damages due floods through non-structural and structural measures. Carefully strategy may assist in decision making to divert certain portion of discharge for damming / pond storage for drinking/ small scale agriculture, dispersion of non-storable water at low cost to pre-demarcated flood plains. Unavoidable flooding could be catered through preparation of proper flood risk zones and issuance and communication of flood forecast with reasonable length of lead time for evacuation of areas in extreme cases to reduce human live loss, loss of live stalk, precious household and commercial commodities. Multi-faceted approach would be required to address the challenges in flash flood risk management in Rajanpur, one of the more vulnerable in term of data-scarcity. Improving data availability, enhancing early warning systems, strengthening emergency response planning, and addressing infrastructure, community preparedness, and reducing institutional and financial constraints are major steps forward.

The august 2022 flood in Rajanpur shows a glimpse of devastation and enormity that can further rise under the warming climate. The destructive flood which badly hit the overall district. This is incomparable to any recent events in terms of temporal scale and vast spatial scale. In all disasters, flood event is ranked second in human mortality, while this was the greatest event as per district government, displaced about thirty million people in Pakistan and 2.5 million in rajanpur district. Using pre and post flood assessments, we examined the damages rapidly right after flooding in Punjab. The extent of flood damage in 2022 highlights the need for non-structural and structural control measures both required a significant investment.

For sustainable development, disaster risk reduction (DRR) policies & SGDs should be implemented into the affected regions. Employing the rapid approach and timely insights into DRR with geospatial mapping and analysis with appropriate tool like Analytical Hierarchy Process (AHP), which shall be beneficial for FRM. DRR through effective FRM will help in maximizing flood benefits with minimum unavoidable damages in future by improving data acquisition, development of proper flood forecasting, flood risk management models, improving building codes, development of early warning communication system, informing and raising awareness to the public, strengthening early response and mitigation measures.

5. Conclusion

Flash flood risk management in data-scarce regions requires a concerted effort to address the challenges identified in this study. Following are the Challenges along with the solutions for a flood risk management in Data scarce regions like Rajanpur. From 2010 to 2022 in District rajanpur torrential flood has damaged more than 120,000 houses with crops affected more than 550,000 acres 39 Lives lost and 590 animals perished. The fact is lot of the stated damages could be averted by deploying effective flood risk management system. The flood damages could be divided into two parts: avoidable and unavoidable and there solution must be sought separately.

5.1 Limited Data Availability

Data scarcity hinders accurate flood forecasting, demarcation of flood risk zones, flood risk assessment. Historical rainfall records, river flow data, relevant hydrological data and physiographic data would be required to suitable develop / simulate flood forecasting, flood management model.

In the absence of sufficient ground gages the alternative data sources (e.g., remote sensing) could be used for the development of appropriate models.

5.2 Risk Mapping Challenges

The preparation of flood risk maps depends on accurate hydrological data along with physiographic data including topographic details, land use & land cover, and vulnerability information.

Acquisition of hydrological data along with usage of remotely sensed data of the catchment and previous extent of floods could be benefited to develop flood risk zoning maps.

5.3 Forecasting Accuracy

Developing spatially accurate flood forecasts is challenging due to data scarcity. Along with usage of remotely sensed weather data, the installation of sufficient number of rainfall, temperature and discharge gages to cover the spatial diversity of hydrological parameters to validate the remote observation would be essential to assist in developing RR model. The physiographic data of sufficient spatial resolution, depending upon selected RR model, would be further required. The accuracy of flood forecasting model would rely on the quality of data, performance of RR and runoff routing model (if included).

5.4 Infrastructure Limitations:

Existing drainage systems may not handle intense rainfall storm induced rapid flooding. Integration of low-impact development practices (nature-based solutions) to enhance infiltration and reduce runoff with flood protection infrastructure to prevent the remaining portion of flood peak would reduce burden on flood protection structure.

5.5 Absence of holistic Flood Risk Management Cycle

Existing flood handling is the combination of fragmented measures taken for prevention, preparedness, response and recovery with limited effectiveness.

The floods could be handled more effectively by running a holistic system under the comprehensive policy document with detailed regulation for allocation of roles and responsibilities of different bodies to develop and operate the system in integrated manner for the prevention of avoidable flood damages, preparedness for reaping benefits from the flood water and minimizing damages of unavoidable flood peak through combination of structural and non-structural measures, quick response for damage reduction and the infrastructure recovery and rehabilitation in post flood period.

Declaration of competing interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper and also declare that they have data with the permission from relevant department/ sources.

Data availability: The authors do not have permission to share data.

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