SEED

POLICY RECOMMENDATIONS ON CLIMATE ADAPTATION AND RESILIENT PLANNING

(February 2024)

EXECUTIVE SUMMARY

In recent years, worsening climate change has further strained Pakistan's already stressed water and agriculture resources. Higher temperatures, shrinking glaciers, and a rise in the frequency and intensity of droughts and floods are just a few consequences of rapidly accelerating climate change. In 2022, Pakistan suffered a devastating loss of life and catastrophic damage due to unprecedented floods. Developing strategies to prevent flooding and build resilience is essential for protecting communities and mitigating extreme weather events.

This study, as per the Government of Khyber Pakhtunkhwa (GoKP) requirements, carried out climate-inclusive hydrological modelling to project floods at various return periods for various basins in Khyber Pakhtunkhwa (KP). The projected flood estimates will provide a baseline for well-informed policy decisions aimed at resilient development and rehabilitation of vulnerable communities. In particular, this intervention will augment the climate-resilient planning and designing process of damaged and vulnerable infrastructure assets.

A comprehensive climate change assessment and report detailing the hydrological models used to make precipitation and flood projection have already been submitted. According to the study's findings, the Gomal River Basin shows the highest increase across the study area. The projected increase in 100-year return flood is 98.6%, 92.9%, and 72.9% for 2011-2040, 2041-2070, and 2071-2100 under SSP 2-4.5 scenario. The rise in 100-year flood under SSP 5-8.5 is projected to be 109.1%, 84.9%, and 76.4% for 2011-2040, 2041-2070, and 2071-2100.

Similarly, the Upper Indus Basin, shows the second highest increase across the study area. The increase in 100-year return flood is 36.8%, 59.1%, and 57.9% for 2011-2040, 2041-2070, and 2071-2100 under SSP 2-4.5 scenario. The rise in 100-year flood under SSP 5-8.5 is projected to be 42.3%, 65.4%, and 67.4% for 2011-2040, 2041-2070, and 2071-2100.

Additionally, the Swat, Chitral, Kabul, Kurram, Tank, and Kunhar river basins also show an increase in 100-year floods. The increase in 100-year flood ranges between 10% to 40% in various time periods under both scenarios. The maximum increase in various return period may occur in different future time periods.

These estimated elevations in various return period floods are also significantly likely to increase the flow of sediment, boulders, and debris in the Gomal, UIB, Kunhar, Swat, Chitral and Kabul River basins. The deposition of these sediments, boulders and debris may block water ways and reduce river carrying and reservoir capacities, which is likely to enhance the likelihood of flooding and extensive damage. Moreover, climate change is likely to also increase the risk of Glacier Lake Outburst Flood (GLOF) events, which may also deposit large quantities of boulders and debris (particularly in the UIB, Chitral and Swat River Basin).

Based on the calculated precipitation and flooding estimates, this report provides a roadmap of policy recommendations for climate change adaptation and climate-resilient infrastructure planning. These measures include the development of a floodplain zoning policy framework, adoption of land use guidelines that prevents unregulated urbanization in the watersheds of rivers, and the development of stormwater management planning standards. The implementation of these policy measures will allow the GoKP to fulfil its mandate by preventing devastating events like the floods of 2022 from recurring, through the establishment of climate-resilient public infrastructure and enhanced disaster preparedness.

CONTENTS

1. INTRODUCTION

1.1. CONTEXT

Pakistan ranks among the top ten countries most affected by climate change worldwide (Germanwatch, 2021)[1]. Historically, devastating floods, such as those seen in the floods of 2010 and 2022, have caused considerable loss of human life and economic hardship for the country. According to initial reports dated June 15, 2022 to September 12, 2022, a total of 303 people lost their lives due to heavy floods in the province of Khyber Pakhtunkhwa (KP). Over 73,000 houses were damaged, in addition to more than 750 schools and 80 health centres, while over 60,000 acres of crops and 470 irrigation systems were destroyed. Furthermore, road networks exceeding 1,500 kilometres and nearly a hundred bridges were either badly damaged or destroyed, amounting to damages worth approximately 18.2 billion Pakistani Rupees (PKR).

Given the significant cost and high risk of future disasters, the government must adopt new tools and technology to develop climate resilient infrastructure that protects people's lives and livelihoods, especially those of vulnerable segments of the population, such as women and children. Climate change-inclusive hydrological models are one such tool for enhancing our understanding and predictability of climate behaviour.

In (), Adam Smith International's Sustainable Energy and Economic Development (SEED) program provided technical assistance to the Government of KP (GoKP) for the rehabilitation of flood-damaged infrastructure. The project, named "Integrated Climate Adaptation and Disaster Resilience Assessment of Critical Infrastructure Assets in Khyber Pakhtunkhwa," aimed to repair roads and bridges that had been damaged in the 2022 floods. The GoKP mandated that these infrastructure assets must be climate resilient. Accordingly, hydrological analysis during the design process did not simply consider historical flood flow as per the conventional approach. Instead, specific climate change projections were made for each asset in the project. This projected climate data was then used to estimate expected runoff based on the characteristics of corresponding watersheds. The flood frequency analysis then analysed both historical stream/river flow data and flows expected under climate change scenarios. The results revealed deficiencies in the conventional design approach in terms of high flood levels (HFLs) corresponding to various return periods, scour depths, and velocities. Given the new design approach's effectiveness in improving climate resilience of critical infrastructure, the GoKP () that climate change projections and consequent flood flows should be determined for all critical river basins in the province. This data could then be utilized by various government departments in the planning and design of public infrastructure.

Based on the GoKP's requirements, the current study carried out climate-inclusive hydrological modelling to project floods at various return periods for various basins in KP. The study also provides a roadmap of policy recommendations for climate change adaptation and climate-resilient infrastructure planning.

1.2. SCOPE OF THE ASSIGNMENT

1.2.1. OBJECTIVES

This study aims to support the GoKP in carrying out a hydro-climatic modelling exercise to estimate the magnitude and frequency of future floods in the Indus River basin of KP. The projected flood estimates will provide a baseline for well-informed policy decisions aimed at resilient development and rehabilitation of vulnerable communities. In particular, this intervention will

[1] https://www.germanwatch.org/en/19777

augment the climate-resilient planning and designing process of damaged and vulnerable infrastructure assets.

The current study's objectives are summarized in Figure 1.

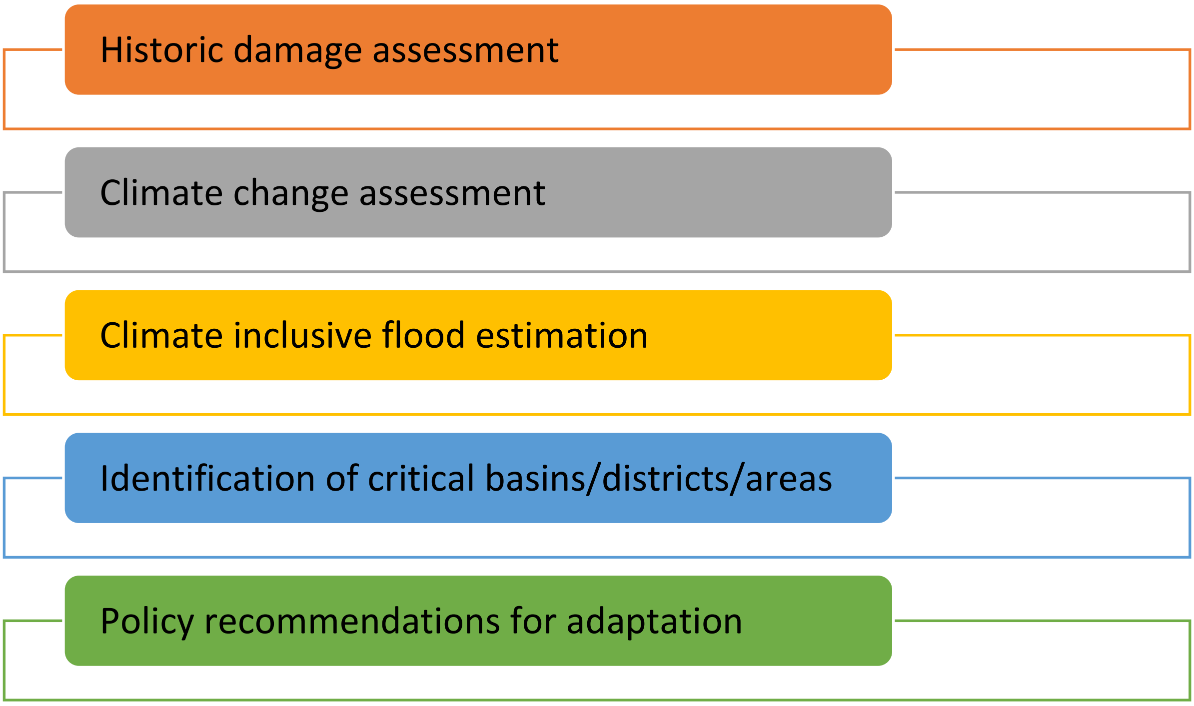

Figure 1. Study Objectives

1.2.2. DELIVERABLES/REPORTS

The consultants' team were asked to submit the following reports:

(i) **D-1: Inception Report.** A report outlining the proposed study approach and methodology, a detailed workflow chart, and a staffing and deliverables schedule to be submitted to SEED within two weeks of the commencement of services

(ii) **D-2.1: KP Climate Change Assessment.** A report providing a comprehensive climate change assessment with a focus on floods in various river basins in KP, to be submitted to SEED within six weeks of the commencement of services.

(iii) **D-2.2: Report on Climate Change-Inclusive Flood Modelling for the Indus River Basin in KP.** A report outlining a climate-inclusive flood model and projected estimates at different return periods for various river basins in the KP, to be submitted to SEED within 10 weeks of the commencement of services.

(iv) **D-3: Policy Recommendations for Climate Change Adaptation and Resilient Planning.** A report devising climate resilient planning measures for various river basins, including structural and non-structural measures based on eco-system and nature-based adaptation, green infrastructure, early warning systems, and grey infrastructure, to be submitted within 14 weeks of the commencement of services.

The current report is Deliverable D-3. It outlines policy recommendations for climate change adaptation and resilient planning.

2. FLOOD LOSSES AND DAMAGES: CASE STUDY FIELD VISITS

2.1. Historic Flood Events and Damages

The statistics of Pakistan's major floods, according to the Federal Flood Commission (FFC), are listed below. The flood in 2010 resulted in the most damages and flooded area (160,000 square kilometres). Other major floods included the floods of 1956, 1973, 1976, 2010 and 2022.

Table 1. Major Floods in Pakistan[2]

S. No.	Year	Direct Losses (US$ Million) @1US$ = PKR 86	Fatalities	Affected Villages	Flooded Area (Square Kilometres)
1	1950	488	2190	10000	17920
2	1955	378	679	6945	20480
3	1956	318	160	11609	74406
4	1957	301	83	4498	16003
5	1959	234	88	3902	10424
6	1973	5134	474	9719	41472
7	1975	684	126	8628	34931
8	1976	3485	425	18390	81920
9	1977	338	848	2185	4657
10	1978	2227	393	9199	30597
11	1981	299	82	2071	4191
12	1983	135	39	643	1882
13	1984	75	42	251	1093
14	1988	858	508	100	6144
15	1992	3010	1008	13208	38758
16	1994	843	431	1622	5568
17	1995	376	591	6852	16686
18	2010	10000 @ 1US$ = PKR 86	1985	17553	160000
19	2011	3730* @ 1US$ = PKR 94	516	38700	27581
20	2012	2640** @ 1US$ = PKR 95	571	14159	4746
21	2013	2000^ @ 1US$ = PKR 98	333	8297	4483
22	2014	440^^ @ 1US$ = PKR 101	367	4065	9770
23	2015	170 @ 1US$ = PKR 105	238	4634	2877
24	2016	6# @ 1US$ = PKR 104.81	153	43	
25	2017	-	172		
26	2018	-	88		
27	2019	-	235		
28	2020	-	409		
29	2022	30,000 @ 1US$ = PKR 225	1739	6631	85,000
	Total	**68,225**	**15199**	**203,704**	**701,558**

* Economic Survey of Pakistan 2011-12
** NDMA (http://www.claimsjournal.com/news/international/2012/10/05/214891.htm)
^ Thomson Reuters Foundation (http://www.trust.org/item/20130909134725-rm708/)(Agriculture sector)
^^ Economic Survey of Pakistan (2014-15)

Source Document: Federal Flood Commission, Annual Report 2022

[2] Office of the Chief Engineering Advisor & Chairman Federal Flood Commission, Annual Report 2022 (By Ministry of Water Resources Govt. of Pakistan)

Using data from the KP Provincial Disaster Management Authority, a list of major natural hazard events that occurred in KP from 1992 to 2023 has been compiled and presented in Table 2.

Table 2. Natural Hazard Events in KP[3]

S. No.	Hazard Description	Year	Spatial Coverage
1	Flood	September 1992	KP, Punjab
2	Flood	July and August 2007	KP
3	Flood	July 2010	KP/Pakistan
4	Flood	August 2011	District Kohistan, KP
5	Flood	September 2012	KP, Upper Sindh, Southern Punjab and Balochistan regions
6	Flood	September 2014	KP, Punjab, GB, Sindh
7	GLOF	2014-2015	GB, Chitral
8	Flood	March 2016	KP Northern Areas
9	Flood	April 2019	KP, Punjab, Balochistan
10	GLOF	July 2019	Golen Valley District Chitral Lower
11	Avalanche	March 2020	Nathia Gali District Abbottabad
12	GLOF	July 2020	Golen Valley District Chitral Lower
13	Cloud Burst	August 2020	Districts Kohistan, Swat & Shangla
14	Avalanche	January 2021	District Mansehra
15	Wind Storm	April 2021	District Peshawar
16	Wind Storm	June 2021	Districts of KP
17	Cloud Burst	September 2021	District Torghar
18	Landslide	January 2022	District Shangla
19	Flood	August 2022	KP/Pakistan
20	Avalanche	January 2023	Usheri Darra, District Dir Upper
21	Landslide	April 2023	Torkham, District Khyber
22	Wind Storm	June 2023	Bannu, Lakki Marwat, Karak and D.I.Khan

Most of KP was been affected by riverine floods in the period spanning 1992 to 2023 (see Figure 3). One of the worst hazards was the Glacier Lake Outburst Floods (GLOFs) in 2014-2015, which effected the regions of Gilgit Baltistan and Chitral.

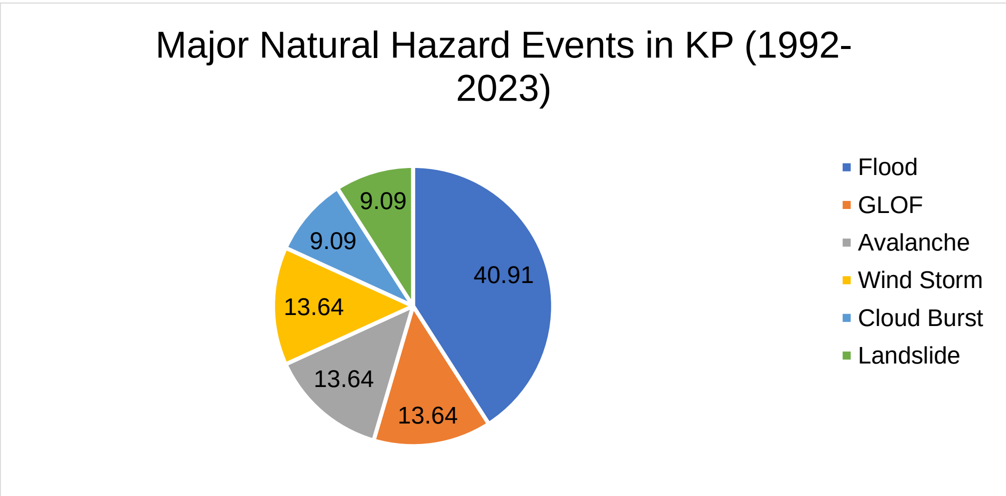

Figure 2. Major Natural Hazard Events in KP (1992-2023)

[3] Monsoon Contingency Plan | 2023 (Provincial Disaster Management Authority, KP).

The National Disaster Management Plan (NDMP) 2012 provided district-wise scores for flood, landslide, earthquake, cyclone, drought, and GLOF risks. The risk scores, ranging from 1 (very low) to 5 (very high), are provided in Table 3.

Table 3. District-Wise Risk Scores for KP[4]

S. No	District	Basin	Flood Risk	Landslide Risk	Earthquake Risk	Cyclone Risk	Drought Risk	GLOF Risk
1	Chitral	Chitral Basin	3	4	2	1	1	3
2	D. I. Khan	Gomal River Basin	5	1	2	2	2	1
3	South Waziristan	Gomal/Tank River Basin	2	2	2	1	1	1
4	Charsadda	Kabul Basin	5	3	5	2	3	1
5	Nowshera		5	3	5	2	3	1
6	Bajaur		3	3	5	2	2	1
7	Peshawar		5	3	5	2	3	1
8	Mohmand		3	4	4	1	2	1
9	Upper Dir		4	5	4	2	2	5
10	Swabi		5	3	5	2	2	1
11	Khyber		3	4	3	1	2	1
12	Mardan		5	3	5	2	1	1
13	Lower Dir		4	4	5	2	1	1
14	Malakand		4	3	5	2	1	1
15	Orakzai	Kabul Basin/Kohat Toi River Basin	2	4	3	2	4	1
16	Kohat	Kohatt/Teri Toi Basin	3	2	3	2	2	1
17	Abbottabad	Kunhar Basin	3	5	5	2	2	1
18	Bannu	Kurram River Basin	4	2	5	2	4	1
19	Lakki Marwat		3	1	3	2	1	1
20	North Waziristan		2	2	2	1	2	1
21	Kurram		3	2	2	1	1	1
22	Hangu	Kurram River Basin/Kohat Toi River Basin	3	3	4	2	3	1
23	Karak	Kurram River Basin/Teri Toi Basin	2	2	2	1	1	1
24	Swat	Swat Basin	5	5	4	2	2	5
25	Tank	Tank Zam River Basin	4	1	3	2	4	1
26	Shangla	UIB at Tarbela	5	4	5	2	4	5
27	Mansehra		4	5	4	2	1	5
28	Buner		5	4	4	2	4	1
29	Batagram		3	4	4	2	3	5
30	Haripur		3	5	4	2	1	1
31	Kohistan		3	4	3	1	1	4

[4] *Source: National Disaster Management Plan – 2012, Note: Number of districts are as per NDMP-2012.*

Furthermore, the river-wise measured flood data for the study area has been assessed for baseline floods, minor floods, moderate floods, severe floods, and very severe floods in KP (see Table 4). The data is also presented in Figure 4 to Figure 16. The data shows that most of the severe and very severe floods occurred in the past 15 years.

Table 4. Annual Peak Discharges/Floods for Rivers in KP

S. No.	Name of River/Khwar /Nullah	Data Availability of Annual Peak Discharges	Baseline Floods		Minor Floods		Moderate Floods		Severe Floods		Very Severe Floods	
			Year	Limit (cumecs)	Year	Limit (cumecs)	Year	Limit (cumecs)	Year	Limit (cumecs)	Year	Limit (cumecs)
1	Indus River at Tarbela Upstream	1982-2020, 2022	-	Less than 7082	1982,1984, 1985,1991, 1992,1993, 1996-2004, 2007-2009, 2011-2014, 2016-2022	7082-10623	1983,1986, 1988-1990, 1994-1995, 2005-2006, 2015	10623-14164	-	14164-18414	**2010**	Greater than 18414
2	Kabul River at Nowshehra	2002-2013, 2016-2022	2002,2004, 2007,2008	Less than 1700	2003,2011, 2012,2018, 2021	1700-2266	2005,2019	2266-2833	2006,2016, 2020	2833-3399	2009,**2010**, 2017,**2022**	Greater than 3399
3	Kabul River at Adezai Bridge	2005-2019, 2022	2006,2018, 2019	Less than 850	2005,2007, 2009,2011, 2012,2017	850-1416	**2010**,2013, 2014,2015, 2016	1416-1983	-	1983-2266	**2022**	Greater than 2266
4	Kalpani River Baghdada Mardan	2009-2022	2009,2011, 2012,2014, 2016,2017, 2020,2021	Less than 567	2015	567-1133	2013,2018, 2019, **2022**	1133-1416	**2010**	1416-1841	-	Greater than 1841
5	Kalpani River Chuki Nallah Risalpur	2000-2022	2001,2005, 2007,2011, 2012,2014, 2016,2021	Less than 567	2000,2002, 2003,2004, 2008,2009, 2013,2015, 2017,	567-1133	2006,2018, 2022	1133-1416	-	1416-1841	**2010**	Greater than 1841
6	Swat River at Chakadara	1988-2022	1989-1990, 1993-1994, 1996-2000, 2002-2004, 2007-2009,	Less than 850	1991,1992, 2001,2005, 2006,2013, 2020,2021	850-1416	1988,1995	1416-2125	-	2125-2833	**2010,2022**	Greater than 2833

S. No.	Name of River/Khwar /Nullah	Data Availability of Annual Peak Discharges	Baseline Floods		Minor Floods		Moderate Floods		Severe Floods		Very Severe Floods	
			Year	Limit (cumecs)	Year	Limit (cumecs)	Year	Limit (cumecs)	Year	Limit (cumecs)	Year	Limit (cumecs)
			2011-2012, 2014-2019									
7	Swat River at Khwazakhela	2005-2022	2007,2009, 2012,2014, 2015,2017, 2018,2019, 2021	Less than 850	2008,2011, 2013,2016, 2020	850-1275	2005	1275-1700	-	1700-2266	2006,**2010, 2022**	Greater than 2266
8	Swat River at Munda Headworks	2005-2022	2009,2014, 2021	Less than 1133	2006,2018, 2019,2020	1133-1700	2005,2007, 2011,2016	1700-2266	2008,2012, 2013	2266-4249	**2010,2022**	Greater than 4249
9	Panjkora at Shigo Kach	1961-2011	1961-1963,1967, 1970,1971, 1973,1974, 1976,1977, 1979-1985, 1987-1989, 1993,1999, 2000-2004, 2008,2009, 2011	Less than 567	1964,1965, 1967,1968, 1969,1972, 1975,1978, 1986,1990, 1991,1992, 1994,1995, 1996,1997, 1998,2006	567-850	2005,2007	850-1416	-	1416-2125	**2010**	Greater 2125
10	Naguman River at Charsada	2005-2018, 2022	2008,2011, 2012,2016, 2017,2018	Less than 283	2006,2007, 2009,**2010**, 2013,2014, 2015,**2022**	283-567	-	567-850	-	850-1416	2005	Greater than 1416
11	Jindi River at Charsada	2004-2019, 2022	2004,2005, 2012,2013, 2014,2015, 2016,2017, 2018, 2019	Less than 212	2006,2009, 2011	212-283	2007	283-425	-	425-567	**2008,2010, 2022**	Greater than 567
12	Khiali River at Charsada Road	2004-2022	2004,2011, 2012,2014, 2015,2016, 2017,2018, 2019, 2021	Less than 1133	2007,2008, 2009,2013, 2020	1133-1700	2005, 2006	1700-2266	**2022**	2266-3399	**2010**	Greater than 3399

S. No.	Name of River/Khwar /Nullah	Data Availability of Annual Peak Discharges	Baseline Floods		Minor Floods		Moderate Floods		Severe Floods		Very Severe Floods	
			Year	Limit (cumecs)	Year	Limit (cumecs)	Year	Limit (cumecs)	Year	Limit (cumecs)	Year	Limit (cumecs)
13	Shah Alam River at Takht Abad	2010-2020, 2022	2016	Less than 142	2011,2014, 2017, 2019, 2020	142-212	2012,2013, 2018	212-354	**2022**	354-425	**2010**	Greater than 425

The 2010 floods were one of the worst floods in Pakistan's history. A total of 1,985 people lost their lives and 1,608,184 houses were damaged or destroyed, while 17,553 villages and a total area of 160,000 km^2 was affected[5].

Similarly, the mega flood of 2022 killed more than 1,700 people, one-third of them children and affected 33 million people, eight million of whom were displaced. The flood's damages were even worse than those of the 2010 flood, estimated at US$14.9 billion, with an estimated total loss of US$15.2 billion and total needs of US$16.3 billion.

The most affected economic sectors and their reconstruction and recovery needs are provided in Table 5[6].

Table 5. Damages, Reconstruction, and Recovery Needs

Damages	
Description	**Damages (Trillion PKR)**
Housing	1.2
Agriculture, Food, Livestock, Fisheries	0.8
Transport and Communication	0.701
Reconstruction and Recovery Needs	
Housing	0.854
Agriculture, Food, Livestock, Fisheries	0.592
Transport and Communication	1.1

A breakdown of damages, losses, and recovery needs at the country and province-level are provided in Table 6. The data is sourced from the Post-Disaster Needs Assessment 2022 Report by the Ministry of Planning Development and Special Initiatives.

Table 6. Damages, Losses, and Recovery Needs by Province

	Damage		Loss		Needs	
Region	**Region (Billion PKR)**	**(Million US$)**	**(Billion PKR)**	**(Million US$)**	**(Billion PKR)**	**(Million US$)**
Balochistan	349	1,625	541	2,516	491	2,286
Khyber Pakhtunkhwa	201	935	141	658	168	780
Punjab	111	515	122	566	160	746
Sindh	1,948	9,068	2,444	11,376	1,688	7,860
Cross-Provincial	587	2,731	14	67	975	4,540
Special Regions	7	32	11	49	10	48
Grand Total	**3,202**	**14,906**	**3,272**	**15,233**	**3,493**	**16,261**

A district-wise breakdown of houses damaged in the 2022 flood in Khyber Pakhtunkhwa were reported by the Provincial Disaster Management Authority (PDMA-KP) and provided in Table 7[7].

[5] Office of the Chief Engineering Advisor & Chairman Federal Flood Commission, Annual Report 2022 (By Ministry of Water Resources Govt. of Pakistan)
[6] National Adaptation Plan Pakistan 2023 (By Ministry of Climate Change and Environmental Coordination)
[7] Monsoon Contingency Plan | 2023 (Provincial Disaster Management Authority, KP)

Table 7. District-Wise Breakdown of Damaged Houses in 2022 Flood in KP

S. No	Division	District	House Damages
1	Bannu	Bannu	1011
2	Bannu	Lakki Marwat	623
3	Bannu	North Waziristan	2203
4	DI Khan	DI Khan	39019
5	DI Khan	South Waziristan	172
6	DI Khan	Tank	3819
7	Hazara	Abbotabad	75
8	Hazara	Battagram	27
9	Hazara	Haripur	58
10	Hazara	Kohistan Lower	1848
11	Hazara	Kohistan Upper	783
12	Hazara	Kolai Palas	3
13	Hazara	Mansehra	168
14	Hazara	Torghar	3
15	Hazara	Hangu	203
16	Hazara	Karak	869
17	Hazara	Kurram	319
18	Hazara	Kohat	0
19	Hazara	Orakzai	49
20	Malakand	Bajaur	1079
21	Malakand	Buner	311
22	Malakand	Lower Chitral	1417
23	Malakand	Lower Dir	1019
24	Malakand	Malakand	339
25	Malakand	Shangla	257
26	Malakand	Swat	1811
27	Malakand	Upper Chitral	1421
28	Malakand	Upper Dir	767
29	Mardan	Mardan	259
30	Mardan	Swabi	259
31	Peshawar	Charsadda	1466
32	Peshawar	Khyber	305
33	Peshawar	Mohmand	371
34	Peshawar	Nowhsera	480
35	Peshawar	Peshawar	180
Total			**62993**

2.2. Findings of Field Visits

This study focused its analysis on two selected locations in KP: the Bahrain River Bridge in Swat and the Kabul River Bridge in Nowshera. Field visits were planned from 9th to 11th February 2024 to these sites to collect data on the damages caused by the 2022 floods.

2.2.1. Bahrain River Bridge

The selected site is located near Bahrain Bazar in District Swat. During 2022 (June to August) Swat experienced heavy rainfall events, which caused severe to very severe floods. The floods significantly damaged infrastructure in nearly all parts of Swat and particularly in Bahrain. The pre- and post-flood satellite images shown below in Figure 17 also show the damaged Bahrain Bridge.

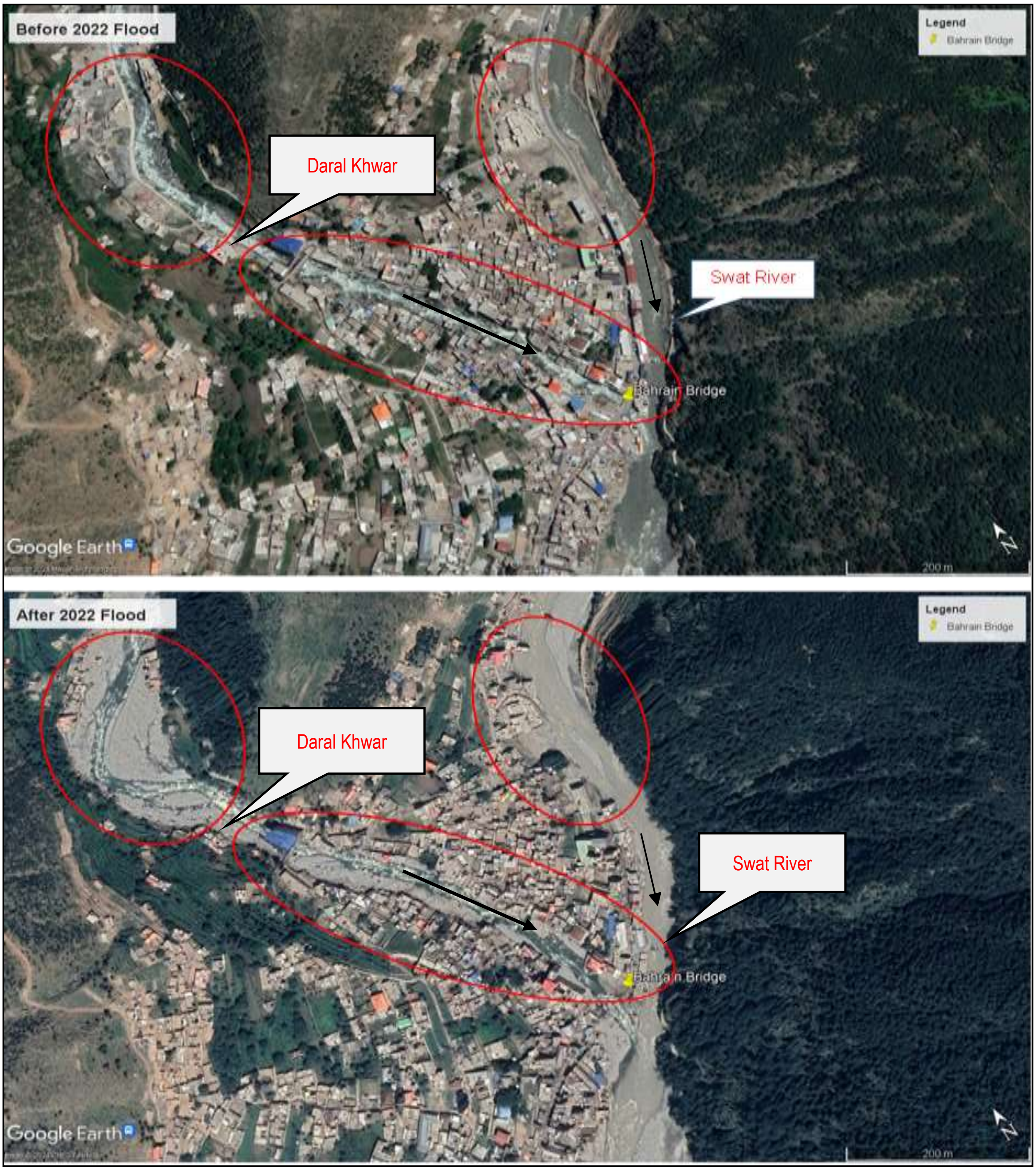

Figure 3. Pre- and Post-Flood Images of Bahrain Bridge, Swat

The researchers who conducted the field visits made the following observations about the effects of the floods:

- Very severe floods occurred in both the main Swat River and the tributary, Daral Khwar.
- Approximately 25 to 30 hotels were fully or partially damaged in Bahrain Bazaar by the Swat Fiver flood and about 8 to 10 hotels, 25 to 30 houses, and one mosque and one middle school near Bahrain Bazaar were damaged by the Daral Khwar flood.
- The RCC Bridge was destroyed by the Daral Khwar flood and the suspension bridge was washed away by the Swat River flood.
- The Daral Khwar Hydro Power Project, located about a kilometre downstream of the Bahrain Bazaar, was also severely damaged.

- High sediment transport resulted in significant deposits and riverbed aggradation. In the main river in Bahrain, the riverbed is now at the same level as or even above houses and roads. The flow of debris from river tributaries were responsible for this high sediment transport. A considerable number of debris were transported into the main river, and the flow of sediments dammed the main river as well as its tributary.
- According to the local community, the riverbed level of Daral Khwar was previously situated around 25 to 30 feet beneath the main bridge. Currently, it is approximately only 8-10 feet below than the bridge.
- The flood depth from the current river bed was approximately 26 feet for both the Swat River and Daral Khwar.
- In certain areas, bank erosion was extensive, with buildings either scoured and undermined or pulled into the river by sliding embankments.
- Much of the damage was due to spatial human-nature conflict. At the time of the 2010 floods, numerous buildings alongside the riverbed had been washed away. However, they were rebuilt at the same locations afterwards only to be washed away in the 2022 floods. Despite this, buildings were once more rebuilt at the same locations.
- The residual risk of the 2022 floods is very high in Bahrain because of riverbed aggradation, which has led to a decline in the river's carrying capacity. Eroded banks along residential and commercial areas pose future risks.

Figure 4. Damages to Hotels in Bahrain Bazar

2.2.1.1. Collection of Samples for Hydraulic Modelling

Sediment size is one of the key input data in hydraulic modelling. Riverbed sediment analysis is also critical for understanding the dynamics of rivers, including sediment transport, erosion, and deposition processes. For this purpose, nine samples were collected from Daral Khwar and three samples were collected from the main Swat River near Bahrain Bazar (see Figure 21). The collected samples then underwent sieve analysis. The grain size distributions are provided in Table 9 to Table 12 (for details see **Annexure A**).

Table 8: Particle Size Distribution of Sediment Samples from Swat River at Bahrain

Test Date	Location	D_{50} (mm)	D_{95} (mm)	Grain Size Distribution		
				Gravel %	Sand %	Silt/Clay %
11/2/2024	MM-1, Main River (Mid-Section)	6	30	64.7	27.2	8.1
11/2/2024	MR-2, Main River (Right Abutment)	6.4	32	70.1	25.7	4.1
11/2/2024	ML-3, Main River (Left Abutment)	6	10.5	70.8	27.1	2.1

Table 9: Particle Size Distribution of Sediment Samples from Daral Khwar at Bahrain Bridge (Right Abutment)

Test Date	Location	D_{50} (mm)	D_{95} (mm)	Grain Size Distribution		
				Gravel %	Sand %	Silt/Clay %
11/2/2024	TRA-1, Tributary River/Daral Khwar (Right Abutment)	0.6	5	4.9	89.4	5.7
11/2/2024	TRA-2, Tributary River/Daral Khwar (Right Abutment)	0.7	21	19.8	76.3	4
11/2/2024	TRA-3, Tributary River/Daral Khwar (Right Abutment)	0.6	3	2.2	96.8	1
Average		0.63	9.67	8.97	87.50	3.57

Table 10: Particle Size Distribution of Sediment Samples from Daral Khwar at Bahrain Bazar (Mid-Section)

Test Date	Location	D_{50} (mm)	D_{95} (mm)	Grain Size Distribution		
				Gravel %	Sand %	Silt/Clay %
11/2/2024	TM-1, Tributary River/Daral Khwar (Mid-Section)	6	38	52.7	46	1.3
11/2/2024	TM-2, Tributary River/Daral Khwar (Mid-Section)	6	30	54.6	40.7	4.7
11/2/2024	TM-3, Tributary River/Daral Khwar (Mid-Section)	4.5	30	48	47	5
Average		5.50	32.67	51.77	44.57	3.67

Table 11: Particle Size Distribution of Sediment Samples from Daral Khwar at Bahrain Bridge (Left Abutment)

Test Date	Location	D_{50} (mm)	D_{95} (mm)	Grain Size Distribution		
				Gravel %	Sand %	Silt/Clay %
11/2/2024	TLA-1, Tributary River/Daral Khwar (Left Abutment)	6	28	69.6	24.1	6.3

Test Date	Location	D_{50} (mm)	D_{95} (mm)	Grain Size Distribution		
				Gravel %	Sand %	Silt/Clay %
11/2/2024	TLA-2, Tributary River/Daral Khwar (Left Abutment)	5.3	18	57.3	32.4	10.3
11/2/2024	TLA-3, Tributary River/Daral Khwar (Left Abutment)	5	19	50	34.2	15.8
Average		5.43	21.67	58.97	30.23	10.80

The pre- and post-flood sediment sizes were compared using flood management plan for KP (conducted by M/s NESPAK[8]), with the results provided in Table 13. The results indicate that the median particle D_{50} size has decreased significantly after 2022 floods. This suggests that the floods likely transported and deposited finer sediment particles, which are likely to be more susceptible to erosion during future flood events.

Table 12: Comparison of Swat River D50 before and after 2022 Floods

D_{50} Size Near Bahrain Bazar (After 2022 Flood	D_{50} Size at Left D/s Khwazakhela (Before 2022 Flood)
6.13	56

Furthermore, topographic surveys, field visits, sample collection, and laboratory analysis of the selected site have been completed. A detailed climate-inclusive flood and hydraulic modelling report will be submitted in the final Deliverable-3 Report.

2.2.2. Kabul River Bridge Nowshera

The second selected site is in district Nowshera, KP. During 2022 (June to August), the Kabul River basin received heavy rainfall events, which resulted in severe to very severe floods. The pre- and post-flood satellite images of the selected site are shown below in Figure 4.

[8] Feasibility Study/Preparation of Comprehensive Flood Management Plan for Khyber Pakhtunkhwa.

Figure 5. Pre- and Post-Flood 2022 Images of Kabul River Bridge, Nowshera

The following observations were noted during field visits to the Kabul River Bridge:

- The Kabul River near Nowshera experienced very severe floods in 2022.
- The 2022 floods breached the flood protection wall near Manakhel Village (located 1.5km U/s of Kabul River bridge), leading to the inundation of nearby villages.
- The 2022 floods inundated the villages of NawaKali, Manakhel, Ghanderi Payeen, and Dab Kali in Nowshera.
- According to the local community, the flood relay entered dozens of settlements, submerged hundreds of acres of crops, and suspended travelling routes. The residents of over 120 houses and more than 30,000 villagers had to be shifted to safe places.
- The Kabul River's flood marks were noted near Nowshera Bridge. The bridge was approximately 24-25 feet above the current riverbed. However, the flood protection wall is only 19 feet high. The floodwaters surged over the protection wall, flooded the surrounding areas.
- Approximately four houses near the Kabul River Bridge were fully washed away by the floods.
- A mosque, private school, and house adjacent to the protection wall were submerged and damaged by the flood.

- The 2022 floods also damaged an electricity transmission tower, which was replaced after flood, located near the Kabul River Bridge.

Figure 6. Submerged House

Figure 7. Damaged Mosque

2.2.2.1 Collection of Samples for Hydraulic Modelling

Five sediment samples were collected from the left and right abutments of the Kabul River Bridge, and three samples were collected from the tributary river near the bridge. After collection, sieve analysis of the samples was conducted, and the grain size distributions have been compiled in Table 15 to Table 17 (for details see **Annexure A**).

Table 13: Particle Size Distribution of Sediment Samples from Kabul River at Nowshera Bridge (Right Abutment)

Test Date	Location	D_{50} (mm)	D_{95} (mm)	Grain Size Distribution		
				Gravel %	Sand %	Silt/Clay %
11/2/2024	NMR-1, Nowshera Main Kabul River (Right Abutment)	0.23	16	7.8	89.7	2.6
11/2/2024	NMR-2, Nowshera Main Kabul River (Right Abutment)	0.22	14	6.3	91.5	2.2
11/2/2024	NMR-3, Nowshera Main Kabul River (Right Abutment)	0.28	11	9.4	87.8	2.8
Average		0.24	13.67	7.83	89.67	2.53

Table 14: Particle Size Distribution of Sediment Samples from Kabul River at Nowshera Bridge (Left Abutment)

Test Date	Location	D_{50} (mm)	D_{95} (mm)	Grain Size Distribution		
				Gravel %	Sand %	Silt/Clay %
11/2/2024	NLM-1, Nowshera Main Kabul River (Left Abutment)	0.18	0.5	0.2	92.6	7.1
11/2/2024	NLM-2, Nowshera Main Kabul River (Left Abutment)	0.28	11	40.8	50.4	8.8
Average		0.23	5.75	20.50	71.50	7.95

Table 15: Particle Size Distribution of Sediment Samples from Nowshera Tributary River

Test Date	Location	D_{50} (mm)	D_{95} (mm)	Grain Size Distribution		
				Gravel %	Sand %	Silt/Clay %
11/2/2024	NT-1, Nowshera Tributary (Mid-Section)	6	29	69.6	27.9	2.6
11/2/2024	NT-2, Nowshera Tributary (Mid-Section)	5.7	30	60	32.2	7.8
11/2/2024	NT-3, Nowshera Tributary (Mid-Section)	0.2	30	28.2	63.7	8.1
Average		3.97	29.67	52.60	41.27	6.17

The pre- and post-2022 sediment sizes were compared using the flood management plan for KP (conducted by M/s NESPAK[9]). The comparison is provided in Table 13. The results indicate that the median particle D_{50} size has decreased significantly after the 2022 floods. This suggests that the flood event likely transported and deposited finer sediment particles, which are likely to be more susceptible to erosion during future flood events.

Table 16: Comparison of Kabul River D50 Before and After 2022 Flood

D_{50} Size (after 2022 Flood)	D_{50} Size (before 2022 Flood)
0.24	17

Topographic surveys, field visits, sample collection, and laboratory analysis of the selected site have been completed. A detailed climate-inclusive flood and hydraulic modelling report will be submitted in the final Deliverable-3 Report.

2.3. Summary of Climate Change Assessment and Hydrological Modelling

Comprehensive reports on climate change assessment and climate-inclusive flood modelling have already been submitted. These reports include 100-year return period precipitation and flood estimates. A study by Deltares[10] reported that the flood extents in 2022 are similar to the historic 100-year flood extents in Pakistan.

[9] Feasibility Study/Preparation of Comprehensive Flood Management Plan for Khyber Pakhtunkhwa.
[10] Appendix-F, Updating the Flood Protection Plan-IV for Pakistan- 2023, Deltares.

The changes in precipitation during the periods of 2011-2040, 2041-2070, and 2071-2100 compared to the 1981-2010 baseline period are provided in Table 19. This analysis is based on the SSP 2-4.5 and SSP 5-8.5 scenarios. Each period under either scenario shows an increase in precipitation.

The increase in precipitation is greater under the SSP 5-8.5 scenario compared to SSP 2-4.5 scenario. The greatest increase in precipitation is projected during the period of 2071-2100 compared to the base period, ranging from 2% to 10% (SSP 2-4.5) and 6% to 17% (SSP 5-8.5). The maximum increase is for the Tankzam basin while the minimum increase is for Kabul basin under SSP 2-4.5 and SSP 5-8.5, respectively. The average increase for all the basins is 5% for SSP 2-4.5 and 12% for SSP 5-8.5, which is nearly the same as for the Kunhar basin with a 4% and 11% increase under SSP 2-4.5 and SSP 5-8.5, respectively.

Table 17: Percentage Change in Precipitation under SSP 2-4.5 and SSP 5-8.5 Scenarios

Name	2011-2040	2011-2040	2041-2070	2041-2070	2071-2100	2071-2100
	SSP 2-4.5	SSP 5-8.5	SSP 2-4.5	SSP 5-8.5	SSP 2-4.5	SSP 5-8.5
Chitral	4%	2%	4%	11%	5%	14%
Gomal	6%	6%	4%	6%	5%	9%
Kabul	4%	3%	3%	4%	2%	6%
Kohat-toi	9%	9%	7%	7%	8%	14%
Kunhar	4%	3%	3%	7%	4%	11%
Kurram	9%	9%	6%	8%	7%	14%
Swat	3%	2%	3%	5%	2%	8%
Tankzam	11%	11%	7%	10%	10%	17%
Teri-Toi	10%	10%	8%	7%	9%	16%
UIB	2%	2%	3%	6%	3%	11%

Similarly, the changes in projected floods during the periods of 2011-2040, 2041-2070, and 2071-2100 compared to the 1981-2010 period under the SSP 2-4.5 and SSP 5-8.5 scenarios for the 100-year return period are provided in Table 20. Each period under either scenario shows an increase in floods. These elevations are greater under the SSP 5-8.5 scenario compared to SSP 2-4.5 scenario, with the Gomal River Basin experiencing the highest increase across the study area.

Table 18: Percentage Change in Flood Volumes under SSP 2-4.5 and SSP 5-8.5 Scenarios

Name	1981-2010	2011-2040	2011-2040	2041-2070	2041-2070	2071-2100	2071-2100
	Historical Period (m^3/s)	SSP 2-4.5	SSP 5-8.5	SSP 2-4.5	SSP 5-8.5	SSP 2-4.5	SSP 5-8.5
Chitral	5179	16.5%	13.6%	24.3%	32.6%	28.8%	52.5%
Gomal	845	98.6%	109.1%	92.9%	84.9%	72.9%	76.4%
Kabul	9575	7.7%	8.8%	10.2%	13.0%	8.8%	27.7%
Kunhar	1760	10.0%	11.0%	5.7%	11.4%	9.7%	20.8%
Kurram	8916	11.8%	9.9%	11.4%	16.8%	14.6%	33.7%
Swat	6195	4.1%	3.3%	9.0%	10.5%	6.5%	18.2%
Tankzam	2294	27.4%	15.8%	14.3%	18.2%	18.2%	31.3%
UIB	17815	36.8%	42.3%	59.1%	65.4%	57.9%	67.4%

The future projected flood estimates emphasize the need for adequate structural and non-structural measures to curtail the adverse impacts of floods. Based on these estimates, we have developed several policy recommendations for climate change adaptation and resilient planning, which are provided in next section.

3. POLICY RECOMMENDATIONS

The findings of this study clearly demonstrate that the province of KP, much like the rest of Pakistan, faces a significant challenge in protecting its citizens from the impacts of climate change-driven hazards over the coming decades. The scale of this challenge is such that a fundamental rethinking of the current policy, regulatory, and development landscape is warranted. Given Pakistan's constrained fiscal space, adaptation measures would need strong support from development partners and access to green climate financing avenues.

Nevertheless, there still exist cost-effective opportunities for the government to back initiatives that can greatly enhance the climate resilience of communities. In fact, most of these interventions may require only technical assistance from international donors instead of heavy financing. Even in the case of physical infrastructure projects that tend to require considerable funding, the implementation of our recommended policy measures may help in two important ways: first, the sheer magnitude of needed physical infrastructure can be reduced; and second, the case for financial assistance would be much stronger if it can be shown that the proposed infrastructure projects are essential and hence not wasteful.

Our policy recommendations are summarized in the following table:

Table 19: Policy Recommendations for Climate Adaptation and Resilient Planning

S. No.	Description	Importance for Climate Resilience [Critical, High, Moderate]	Recommended Commencement Timeline	Expected Timeline for Implementation
1.	Disseminate Study Results	High	Immediate (within 3 months)	3 months
2.	Design a Floodplain Zoning Policy Framework	Critical	Immediate (within 3 months)	9 months
3.	Outline Land Use Policy Guidelines for Urban Growth	Critical	Immediate (within 3 months)	6 months
4.	Draft Stormwater Management Planning Standards and Design Guidelines	Critical	Immediate (within 3 months)	6 months
5.	Set Guidelines for Nature-Based Solutions to Mitigate Floods and Combat Desertification	High	Medium term (within 1 year)	3 months
6.	Engage Local Communities in Data Collection	Moderate	Medium term (within 1 to 2 years)	12 months
7.	Devise Guidelines for Riverbed Materials Use	Moderate	Medium term (within 1 to 2 years)	6 months
8.	Assess Impact of Hydropower Generation	Moderate	Medium term (within 1 to 2 years)	6 months
9.	Address Impact of Climate Change on Agro-Ecological Zones of KP	Moderate	Medium term (within 1 to 2 years)	6 months
10.	Develop Bylaws Mandating White Roofs	Moderate	Medium term (within 1 to 2 years)	3 months

Each of the above recommendations is explained in the following sections, in terms of its relevance to the study findings and its importance with respect to climate change adaptation in the province. Furthermore, where relevant, the weaknesses and structural flaws of existing regulatory framework are also discussed. Moreover, the discussion also identifies the relevant enabling legal/regulatory instruments through which the proposed interventions could be implemented.

Therefore, the basin-level future flood projections suggest carrying out sub-basin level climate change-inclusive flood modelling together with sub-basin-level integrated flood management dynamic adaptation pathways planning for the near, mid, and long-term basis. It is also recommended that the climate-inclusive Climate Risk Vulnerability Risk Assessment (CRVA) should be carried out at the basin and sub-basin levels.

3.1. Disseminate study results

This study's flood projections for the Indus River Basin and its sub-basins can be used to design adaptation initiatives that can mitigate the effects of climate change and protect vulnerable communities. Therefore, given their value, the results of this study should be shared with all provincial government departments and relevant research institutions.

As there may be some genuine concerns in widely sharing detailed information about historic and projected river/stream flow measurements, criteria can be established to determine which departments and organizations are eligible to receive this data. Furthermore, standard operating procedures (SOPs) – such as access permissions and storage standards – that ensure the data is used responsibly can be established. However, no issues are anticipated in the dissemination of climate projections for temperature and precipitation.

To better assure the effective utilization of this data, training workshops should be arranged for various government departments. These workshops can help public officials understand how these climate change projections were developed and learn how to use and apply the data in their respective domains. Accordingly, the design of the workshops must align with the training needs of a diverse range of government officials, such as administrative, engineering, health, education, and so on.

Some of the anticipated benefits of sharing results, especially with research institutions, is that other scientists can reproduce our study's outcomes and use its findings to expand its scope and refine climate change projections.

3.2. Design a Floodplain Zoning Policy Framework

To minimize human suffering and economic losses from projected future floods because of climate change, designing a flood zoning policy framework for KP is imperative. This recommendation aims to integrate flood risk management into the planning process of land use, so as to retain the natural functions of floodplains, minimize loss of life and property damage caused by flooding, and maximize the benefits of a harmonious existence with floodplains.

The framework should [11]:

i.) Embed climate-resilient flood risk management into existing planning policies and plans by focusing on managing floodplain development.

ii.) Categorize different flood zones according to the probability and severity of flood occurrence. The extent of the flood zones would be a function of the topography of an area instead of arbitrarily prescribed uniform distances throughout the province. For example, flood zones can range from low hazard zones, floodplain fringes, functional floodplains, and flood ways. These zones can then be even further sub-divided.

iii.) Propose guidelines for appropriate land usage for designated flood zones based on risk criteria acceptable for different development activities. For example, a football field may be

[11] Developing Climate Resilient Flood and Flash Flood Management Practices to Protect Vulnerable Communities of Georgia: Floodplain Zoning Policy Framework and Policy Guidance Notes.

built near a river because little harm would be caused if it occasionally floods. However, if a housing scheme is flooded, the expected damages would be devastating. Therefore, residential areas should only be located in an area with low probability of flooding.

iv.) Vulnerability classes for different types of infrastructure should be developed. Examples of such classes include critical infrastructure, emergency services infrastructure; highly-, moderately-, and less- vulnerable infrastructure.

v.) Provide guidelines for managing existing risks to buildings already in high hazard areas through appropriate policy mechanisms, such as flood insurance schemes, installation of flood forecasting and early warning systems, and incentivizing relocation of businesses and households to appropriate flood zones.

A detailed analysis of the existing regulatory framework in relation to floodplain zoning would be too lengthy for this report. However, it is important to note that two legal instruments currently address floodplain zoning: the KP River Protection Ordinance (KP RPO) 2002 and the KP Land Use and Building Control (KP LUBC) Act 2021. The fact that two laws address the same issues creates legal confusion. As part of the KP LUBC Act 2021, amendments were made in other laws to remove duplications of scope in terms related to land use planning and zoning powers to ensure that these powers are vested only in a newly created provincial Land Use and Building Control Council. However, the Act's overlap with the KP River Protection Ordinance 2002 has not been addressed.

Furthermore, although the KP LUBC Act 2021 covers land use and zoning functions for the province, guidelines and policy frameworks that inform and guide the development of land use plans do not exist. Nevertheless, despite the absence of such a framework, the development of district land use plans under the Act has commenced. These plans lack the features essential for floodplain zoning. Moreover, although the KP RPO 2002 contains provisions for demarcating floodplain zones, these provisions are highly problematic as they lack an underlying rational basis.

A comprehensive floodplain zoning framework would ensure that land usage plans align with environmental protection requirements in the floodplains and promote socio-economic growth without jeopardizing the safety of communities.

3.3. Outline Land Use Policy Guidelines for Urban Growth

This study's results suggest that floods of different return periods will increase significantly for every river basin under both SSP 245 and SSP 585 scenarios. However, unless major changes are made in land use guidelines, future floods may significantly exceed this study's projections. The more impervious is the surface area in a catchment area, the larger is the runoff generated, even for the same amount of precipitation. The following figure illustrates this concept graphically:

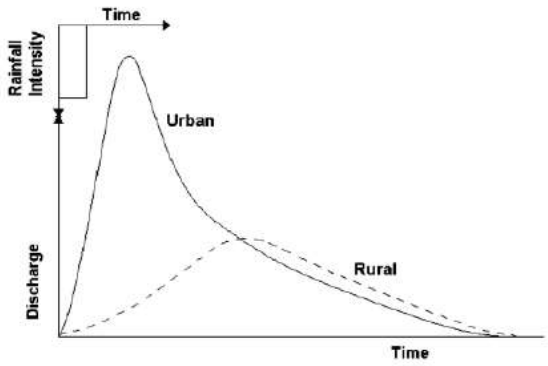

Figure 8. Flood hydrographs for urbanized and rural drainage basins[12]

The above figure shows that the same amount of precipitation results in different discharge (surface runoff) from a watershed with different land use characteristics. Urbanized watersheds have more impervious surfaces, so their peak discharge is considerably higher. The figure also shows that in urbanized watersheds, peak discharge accumulates in a much shorter span of time, thus often leading to flash floods with little time for dissemination of warnings and evacuating vulnerable communities.

While runoff from a watershed is a function of several other factors, the effect of built-up areas can be profound. One study[13] found that for every percentage point increase in the built-up area, the runoff generated from the watershed increased by more than three percentage points. The District Land Use Plan for Nowshera has proposed that the built-up area in the district should be expanded by 50% over a period of 20 years, which could translate into a more than 150% rise in surface runoff.

This study's estimation of water flows and associated flood flows were developed on the basis of current land use characteristics. If, however, these land use characteristics change because of urbanization, then future floods could be considerably more severe than those forecasted in this study. Historic trends show that built-up areas in KP province – as in the rest of the country – have been increasing. This is not just because of an increase in population, as the expansion of built-up areas has even exceeded population growth. With the right policy and regulatory framework, population growth could have been accommodated with a much smaller rise in urbanization.

The underlying reasons for this unchecked urbanization are the structural flaws built into our planning standards. These flaws promote horizontal growth of settlements and a tendancy towards

[12] Dams, J., Batelaan O., Nossent J. and Chormanski J, 2009. Improving hydrological model parameterisation in urbanized catchments: Remote sensing derived impervious surface cover maps. In: Feyen J., Shannon K. and Neville M. (eds), Proceedings of the International Urban Water Conference, Heverlee, Belgium, 15-19 September, 2008.

[13] Jat, M. K., Khare, D., Garg, P. K., & Shankar, V. (2009). Remote sensing and GIS-based assessment of urbanisation and degradation of watershed health. Urban Water Journal, 6(3), 251-263.

expanding road infrastructure to accommodate traffic growth. Moreover, government housing schemes have subsidized large plot sizes, encouraged large housing units in private housing schemes, enacted bylaws that restrict vertical development, and developed transport infrastructure that is almost entirely focused on facilitating personalized vehicle ownership and travel.

The following policy measures are recommended to address this issue:

- Land use guidelines need to be developed that specify the target population densities for various urban and rural areas. Once approved by the Provincial Land Use and Building Control Council, land use plans then must be developed so that they are geared towards achieving those desired population densities. The current practice of developing district land use plans in absence of any guiding standards is highly flawed in terms of flood mitigation and protection of ecological services.

- Guidelines need to be developed for transportation plans and project designs that invariably consider public transport as an alternative to address mobility needs instead of simply designing for expanded capacity of road infrastructure. It is important to note here that this is indeed already included in the Sectoral Guidelines for Major Roads published by the Pakistan Environmental Protection Agency for the purpose of carrying out environmental assessments. However, these guidelines need to be strengthened e.g. by making them part of regulations under the KP EPA Act.

3.4. Draft Stormwater Management Planning Standards and Design Guidelines

The preceding policy recommendation emphasized the importance of controlling urban sprawl and encroachment. However, for urban development that is unavoidable or has already happened, implementing stormwater management measures may mitigate shifts in hydrologic cycle so that infiltration and evapotranspiration are enhanced, surface runoff is reduced, and water quality is improved.

Stormwater management measures establish uniform guidelines of minimum standards that support the planning and design process for new land development, re-development, and infrastructure renewal projects. These guidelines intend to manage plot/building-level and runoff conveyance infrastructure, as well as regulate end-of-pipe discharge, to mitigate impacts of poor design and implementation.

Plot-level and conveyance controls are classified[14] as storage or infiltration controls. Storage controls are designed to detain stormwater, so even though runoff volume does not decrease, the risk of flooding falls because the stormwater runoff does not reach the stream simultaneously. Meanwhile, infiltration controls are necessary for soil moisture replenishment and groundwater recharge. They can enhance water quality but are more suited for the infiltration of clean stormwater, including rooftop and foundation drainage. The pre-treatment of road drainage is necessary to prevent systems from becoming clogged and to protect groundwater quality. Plot-level and conveyance controls include rooftops, parking lots, superpipe storage, reduced plot grading, ponding areas, pervious pipe systems and catch basins, among others.

Furthermore, end-of-pipe stormwater management practices are aimed at mitigating the effects of urbanization that remain after preventative techniques and plot level and conveyance measures have already been applied. These facilities are usually required for flood and erosion control and water quality improvement. Some examples of end-of pipe controls include vegetation and planting techniques and strategies, wet ponds, wetlands, dry ponds, infiltration basins, and oil/grit separators.

Comprehensive design guidelines can help in the selection of effective plot-level, conveyance, and end-of-pipe practices according to physical constraints, such as soil type and depth to groundwater; sizing and configuration; and design details including inlets and outlets, filter media, and distribution pipes. Maintenance and inspection guidelines are also critical to the successful performance of a stormwater management system. These specify SOPs for operations and frequency and protocols for monitoring and inspection. The criteria for a preferred stormwater management system needs to be established that shall consider the cost, technical feasibility, effectiveness, and social acceptability. The overall cost must include capital, operating, and maintenance costs.

Thus, planning standards and design guidelines should be developed for stormwater management in built-up areas. Furthermore, to mainstream the developed standards and design guidelines in regular development projects, the following actions must be implemented:

- The guidelines must be officially designated as regulatory instruments by approving them as regulations under the legal authority of the KP Environmental Protection Act 2014.
- These regulations should extend beyond the housing sector to include industrial estates and roads sectors.

[14] SWM Planning & Design Manual, Ontario Ministry of Environment (MOE), 2003

- The above measures will only be applicable to new projects. However, the potential to improve existing built environment and implement some sustainable SWM interventions exists. This can be encouraged by offering rebates in property taxes and/or municipal services fees to existing property owners.

3.5. Set Guidelines for Nature based Solutions to mitigate floods

Nature-based solutions (NBS) can mitigate several types of hydro-meteorological hazards, such as floods, droughts, landslides, coastal erosion, storm surge, and nutrients and sediment loading. Reforestation and afforestation, wetland restoration, sustainable land management and green infrastructure are examples of NBS to target floods and droughts in Pakistan. The compatibility of nature-based solutions with the existing environment and ecosystems must be considered to achieve fruitful results and justify costs and efforts.

Traditionally, flood mitigation efforts have focused almost entirely on grey infrastructure. Despite their obvious and multi-faceted benefits, adoption of NBS for mitigation of floods and other hazards has not yet been mainstreamed. To effectively plan, design, implement, and monitor NBS projects, guidelines must be developed that focus on elements such as:

- System-wide analysis of the local socio-economic, environmental, and institutional conditions.
- Assessment of the risks and benefits of all the possible measures
- Performance evaluation using quantitative criteria
- Integration of existing ecosystems and native species into the solution
- Long-term monitoring to facilitate adaptive management

3.6. Engage Local Communities in Data Collection

For hydrological analysis, the availability of stream flow data is necessary. As noted in an earlier report of this study, stream flow data are available from WAPDA and the Irrigation Department. However, river gauges are installed at only a few sites on major rivers. Furthermore, the available data has quality issues, with records riddled with inconsistencies, uncertainties, and missing values. This limited availability of reliable data of stream flow measurements hampers assessments in scientific studies.

To collect more data, relevant government agencies could increase the number of gauging stations on rivers and their tributaries. This can be an independent initiative of the government. However, due to budget restrictions, government agencies may not be able to make extensive efforts. In that case, crowd sourcing stream-flow information could be considered as an alternate solution.

Crowdsourcing is the act of collecting ideas, content, or money through large groups of people. The CrowdWater project is one example of crowd-sourcing hydrological data by asking citizens to volunteer and collect data for hydrological forecasting[15]. The University of Zurich developed an application that enables public to take stream flow measurements from locations with or without gauges and then upload them onto a centralized server. This data is publicly available online can be downloaded and shared for use.

[15] https://crowdwater.ch/en/start

Given how cost effective it is, crowdsourcing can be used to collecting river or stream-flow data. Additionally, a few gauge stations should be developed, for which partnerships with educational institutions that can conduct regular data collection, interpretation, and sharing.

Crowdsourcing and partnerships with educational institutes will not only improve data collection at minimal cost but it will also help spread awareness about climate change amongst students, communities, and the general public, thereby improving their adaptation capacities.

3.7. Devise Guidelines for Utilizing Riverbed Materials

Heavy rainfall causes soil erosion and destabilizes fragile hill slopes. Rivers carry debris from upstream areas and deposit them when entering flat terrains. This aggradation process has significant implications for flood impacts, causing the river's carrying capacity to decrease. This leads overflowing floodwaters that inundate areas that may previously have been outside the high hazard floodplain zone.

While sustainable mitigation of aggradation requires NBS, remedial measures must be implemented to alleviate flood consequences. This involves removing riverbed material from affected river reaches. However, given the scale of the issue, this solution may be too costly for the government. Nevertheless, these costs can be offset by using riverbed materials to generate revenue.

Some revenue-generating uses of riverbed materials include construction projects, landscaping, river restoration, and other activities. To promote such uses, it is important to develop standards and guidelines that address:

- Regulations, material specifications, and building codes
- Sustainable extraction practices
- Safety guidelines for workers
- Hydraulic modelling to prevent excessive removal and undesirable impacts on river morphology
- Development of guidelines for the transportation of riverbed materials
- Implementation of Quality Assurance and Quality Control procedures

3.8. Assess Impact on Hydropower Generation

The findings of this study not only point to a significant increase in the likelihood of extreme flood events but also in the frequency and severity of droughts. In fact, during some periods of the year, stream flows could be lower than historic patterns.

This reduction in stream flows will have significant implications for the generation potential of hydropower facilities that do not have water storage components. As hydropower is a major component of Pakistan and KP's energy policy, studying the likely effects of climate change on the generation capacity of hydroelectric power plants is essential.

The current study's forecasts of daily stream flow measurements until the year 2100 can provide a base for future studies to analyse the hydropower generation potential of power plants. Such studies can guide long-term energy planning for the province and the country.

3.9. Address Impact of Climate Change on Agro-Ecological Zones of KP

Recently, the GoKP has made a commendable contribution to identifying agro-ecological zones in KP. However, the underlying basis for this classification was historical temperature and precipitation data. The current study's outcomes imply there will be significant changes in future temperature and precipitation because of climate change. Consequently, the current classification of agro-ecological zones may not remain valid in the future. Therefore, additional studies that update this classification based on our study's forecasts should be carried out.

3.10. Develop Bylaws Mandating Cool/Reflective Roofs

This study's outcomes suggest that the climate in all of KP's river basins will become increasingly warm. This has major implications for the health and well-being of the citizens of KP. One policy measure that can be adopted to mitigate the impact of rising temperatures is the promotion of cool or reflective roofs. The cool roofing technique, which involves whitewashing or coating roofs with reflecting materials, can affect albedo and the environment in several ways. This is a low-cost and effective climate change adaptation and mitigation measure.

Two policy measures can be taken to help promote the adoption of white/reflective roofing:

- First, as part of building bylaws, the government can mandate that all new buildings must have their roofs finished with durable white/reflective materials. Examples of such regulatory measures include planning restrictions aimed at reducing city temperatures through prohibiting dark roofs for all new homes in Sydney, Australia. Similarly, a clause mandating that buildings have white roof coverings was added to the Philadelphia Building Construction and Occupancy Code.
- Second, cool roofs can be incentivized for both new buildings as well as existing ones through financial instruments. Cities in the United States such as Anaheim, Austin, Chicago, Los Angeles, Louisville, and Orlando offer a cool-roof rebate while Baltimore, New York City, Philadelphia, San Antonio, and Texas run programs that install cool roofs for low-income homes.

3. CONCLUSION

This study projects a wetter and hotter climate in the near to distant future. Our climate change-inclusive flood modelling results demonstrate an increase in various return period floods.

The projected flood intensities vary between different basins and return periods:

- The Gomal River Basin shows the highest increase across the study area. The increase in 100-year return flood is 98.6%, 92.9%, and 72.9% for 2011-2040, 2041-2070, and 2071-2100 under the SSP 2-4.5 scenario. The rise in 100-year flood under SSP 5-8.5 is projected to be 109.1%, 84.9%, and 76.4% for 2011-2040, 2041-2070, and 2071-2100.

- Similarly, the Upper Indus Basin shows the second highest increase across the study area. The increase in 100-year return flood is 36.8%, 59.1%, and 57.9% for 2011-2040, 2041-2070, and 2071-2100 under SSP 2-4.5 scenario. The rise in 100-year flood under SSP 5-8.5 is projected to be 42.3%, 65.4%, and 67.4% for 2011-2040, 2041-2070, and 2071-2100.

- In addition, the Swat, Chitral, Kabul, Kurram, Tank, and Kunhar river basins also show an increase in 100-year floods. The increase in 100-year flood ranges between 10% to 40% in various time periods under both scenarios. The maximum increase in various return period may occur in different future time periods.

Furthermore, the potential increase in various return period floods is likely to increase significant sediment, boulders, and debris flows in the Gomal, UIB, Kunhar, Swat, Chitral, and Kabul River basins. The deposition of these sediments, boulders, and debris may block water ways, reduce river carrying capacities (such as witnessed in Swat River during flood 2022) and reservoir capacities (such as witnessed in the Tarbela Dam and Chashma Barrage), and cause extensive damage. Climate change may also increases the risk of Glacier Lake Outburst Flood (GLOF) events, which would also dislocate boulders and debris (particularly in the UIB, Chitral and Swat River Basin).

Based on the study's hydrology forecasts and field visit observations, we recommend several policy recommendations to mitigate the effects of floods and build resilience for vulnerable communities. These measures include designing a floodplain zoning framework, land use guidelines to promote densification and arrest uncontrolled increase in built-up environment, and stormwater management planning and design standards. The adoption of such frameworks will help prevent devastating events like the floods of 2022 from recurring, through the establishment of climate-resilient public infrastructure, strong regulatory frameworks, and enhanced disaster preparedness.