



## Geospatial analysis of flood causes and extent of flood damages in Swat Valley, North Pakistan

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### Abstract:

Floods are the most dangerous and recurring natural hazard that can destroy people's property, lives, and livelihoods, and they occur because of extreme weather events, population expansion, and the lack of effective preparedness measures. The key reasons included unplanned built-up regions, town expansion on the mountain slopes, lack of awareness, and poverty. Floods are considered one of Pakistan's most devastating and recurring natural catastrophes. Similarly, district Swat is a highly prone area to flooding and has been severely impacted by recent floods in 2010, 2016, and 2020. Primary data were acquired through field surveys and direct observation. For micro-level analysis, four villages were selected randomly, i.e. Ningulai, Amamdherai, Shagai, and Paklai. The analysis revealed that floods mainly occurred in summer in July and August in upper Swat, while riverine floods were experienced in lower Swat. The resultant analysis shows that 95 people died in July 2010, 19 in 2016, and 13 in floods in 2020. The comparison of pre-and-post-flood satellite images reveals that significant changes happened in the post-flood scenario, most notably in the water class, and it was found that the area under water bodies has increased in the post-flood situation.

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## 1. Introduction

Swat Valley, a region in the Hindu Kush Mountain ranges north of Pakistan, faces a regular threat in the form of catastrophic floods (Hussain *et al.*, 2023). These specific events destroy the human population and pose substantial economic hardship, ultimately damaging cultivated land and other infrastructure. This research study aims to identify the major causes of flooding and map the damages across the Swat Valley. Moreover, the present study evaluates the variables that actually caused the floods of 2010, 2016, and 2020, as well as the nature of damages in one of the harshly affected areas of District Swat, Pakistan. Socio-economic, topographical and hydro-meteorological aspects were examined to identify the flood-generating factors and related damages (Liu *et al.*, 2019a).

Generally, floods have been particularly destructive in District Swat, and there have been significant floods in 1992, 1995, 1999, 2005, 2010 (Bahadar *et al.*, 2015), 2016, and 2020 with peak discharge of 130000, 57000, 60000, 70000, 175546, 47000, and 46000 cusecs (Munawar *et al.*, 2021). Specifically, flood is a major catastrophe in many parts of the world, and numerous interrelated and intricate factors contribute to flooding (Barros *et al.*, 2015; Caballero *et al.*, 2019). In response to human activities, the frequency of flood recurrences is increasing daily (Khalid *et al.*, 2018). Similarly, floods are naturally generated due to temperature rise, which causes thermal expansion, heavy rain, and glacier melting, as a result, sea level is rising and coastal areas are being accumulated (Halgamuge & Nirmalathas, 2017).

The factors that cause floods are severe rainfall, snowmelting and dam failure (Rahman & Di, 2017). Furthermore, climate change has been identified as a key source of floods worldwide (Sukhwani & Shaw, 2023). Floods are primarily worsened by human activity, such as the construction of buildings in places prone to flooding (Sholihah *et al.*, 2020). Human factors include encroachment in the floodplains, land use change, ecosystem degradation, and deforestation (Rahman & Khan, 2013). Flash floods are sometimes caused by Glacial Lake Outburst Floods (GLOF), cloudbursts, and breaching of dams blocked by landslides (Mahmood & Ullah, 2016; Shrestha & Chaudhary, 2021).

Floods are the most recurrent and damaging hydrological disasters (Rahman & Khan, 2013). Globally, floods affect an estimated 20 to 300 million people annually, mainly in developing countries (Liu *et al.*, 2019b). Flash floods have the highest mortality rate of any natural catastrophe, with around 1,550 casualties yearly across all the continents (Mahmood & Mayo, 2016). Disasters regarding floods and subsequent damages are more predominant in developing countries because of limited resources, high urbanisation and thick population, poor management and resilience to cope with floods. Insufficient flood mitigation measures, both in terms of severity and frequency, have disturbed the livelihoods of millions of people across the globe (Shah *et al.*, 2017; Choo & Yoon, 2024). Weak flood mitigation strategies and limited resources are essential contributors to the increase in flood risk among the rural population, particularly in developing nations (Abbas *et al.*, 2015).

Globally, Pakistan is amongst the most flood-affected countries (Sajjad *et al.*, 2019). Floods, particularly in River Indus and its tributaries, have a long history, as proven by the floods of 1928, 1929, 1950, 1955, 1957, 1959, 1973, 1976, 1977, 1988, 1992, 1995, 1996, 1997, 2003, 2007, 2010, 2013, 2016 and 2020 (Munawar *et al.*, 2021). In Pakistan, Riverine floods occur in low-lying areas during the monsoon season, whereas flash floods occur in hilly and upstream

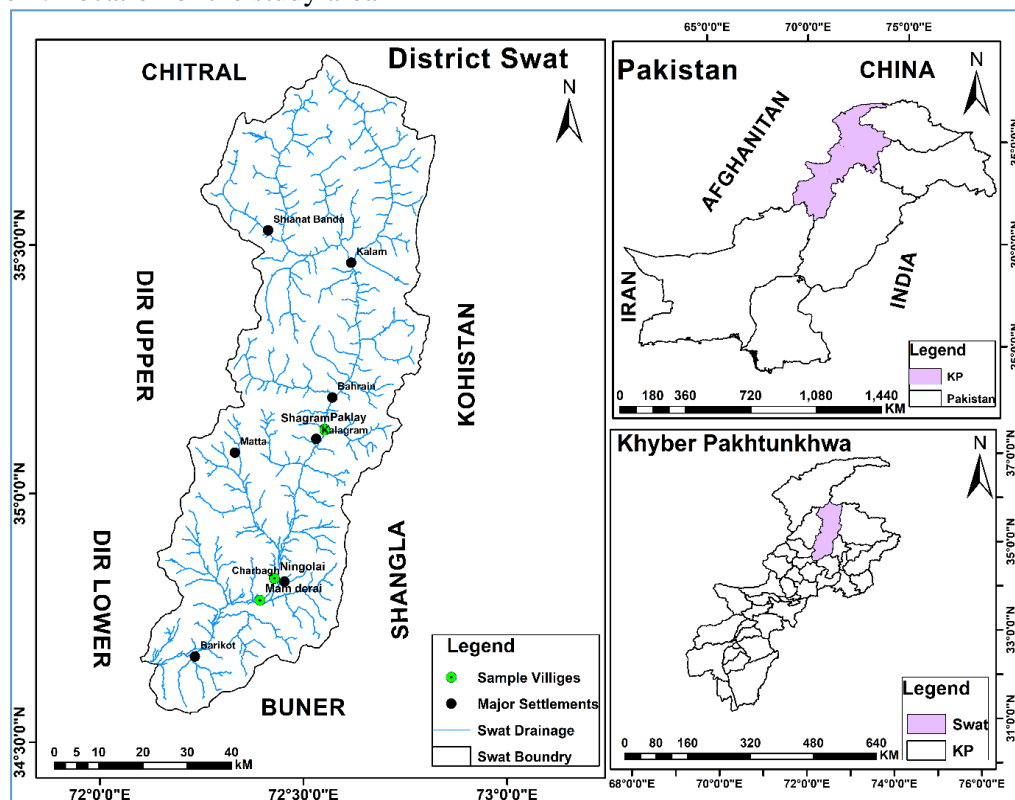
regions (Hashmi *et al.*, 2012). This study aims to calculate the geospatial data regarding floods and the causes and extent of damages in the Swat Valley, North Pakistan. By exploring the environmental dynamics of the study region using advanced technology such as GIS and remote sensing techniques, we can find out the adverse impacts and extent of damages caused by floods. This will pave the way for researchers and decision-makers to mitigate future disasters that happen in the form of floods.

## 2. Methods and material

### 2.1. The study area

District Swat is a crucial district of Khyber Pakhtunkhwa province and is situated in the northwestern part of the province, Pakistan. The district is bordered in the north by Gilgit-Baltistan and Chitral. In the east and southeast are Kohistan, Shangla, and Buner's districts, whereas Malakand, Lower Dir, and Upper Dir districts lie in the eastern side. The study area (Swat) is situated geographically between 34° 35' 59" and 35° 43' 52" North latitude and 72° 08' 53" to 72° 30' 50" East longitude Figure 1).

Figure 1: Location of the study area



Administratively, the study area is divided into seven tehsils, i.e. Khwazakhela, Babozai, Matta, Bahrain, Charbagh, Kabal and Barikot and hold a total geographic area of 5,337 km<sup>2</sup> (506,528 hectares; Pakistan Bureau of Statistics, 2017). According to the 2017 census, the population of District Swat was 2,308,624, out of which 1,136,544 (49%) are female and 1,171,947 and 51% are male, with a population density of 432.57 persons per square km. Moreover, the average annual growth rate of the population was 3.24%.

The elevation of District Swat ranges from 600 to 6500 m above sea level and lies in the temperate zone (Dahri *et al.*, 2011). The warmest month is June, with an average maximum temperature of 33 degrees Celsius. Similarly, January is the coldest month, with average minimum temperatures of -2°C (Dawood *et al.*, 2017). The average annual rainfall ranges from 700 to 1,630 millimetres. The district's soil textures are mostly gravely to stony, sandy loam and gravely sandy loam with igneous and fine-grained rocks that are appropriate for a wide range of crops. Out of the total reported area, 98,054 hectares (19.3%) is cultivated area and 408,474 hectares (80.6%) uncultivated land.

## **2.2. Methods of data collection and analysis**

Data were collected from both primary and secondary sources. The map of the research region was obtained from the Pakistan Survey. Initially, primary data was collected from field surveys through purposive sampling. Secondary data were collected from respective reports, journals, and satellite images. Moreover, field visits were made to obtain information regarding the selected district. The collected data was analysed using computer software like Google Earth Pro, ArcGIS, MS Excel, and SPSS.

### **2.2.1. Primary data acquisition**

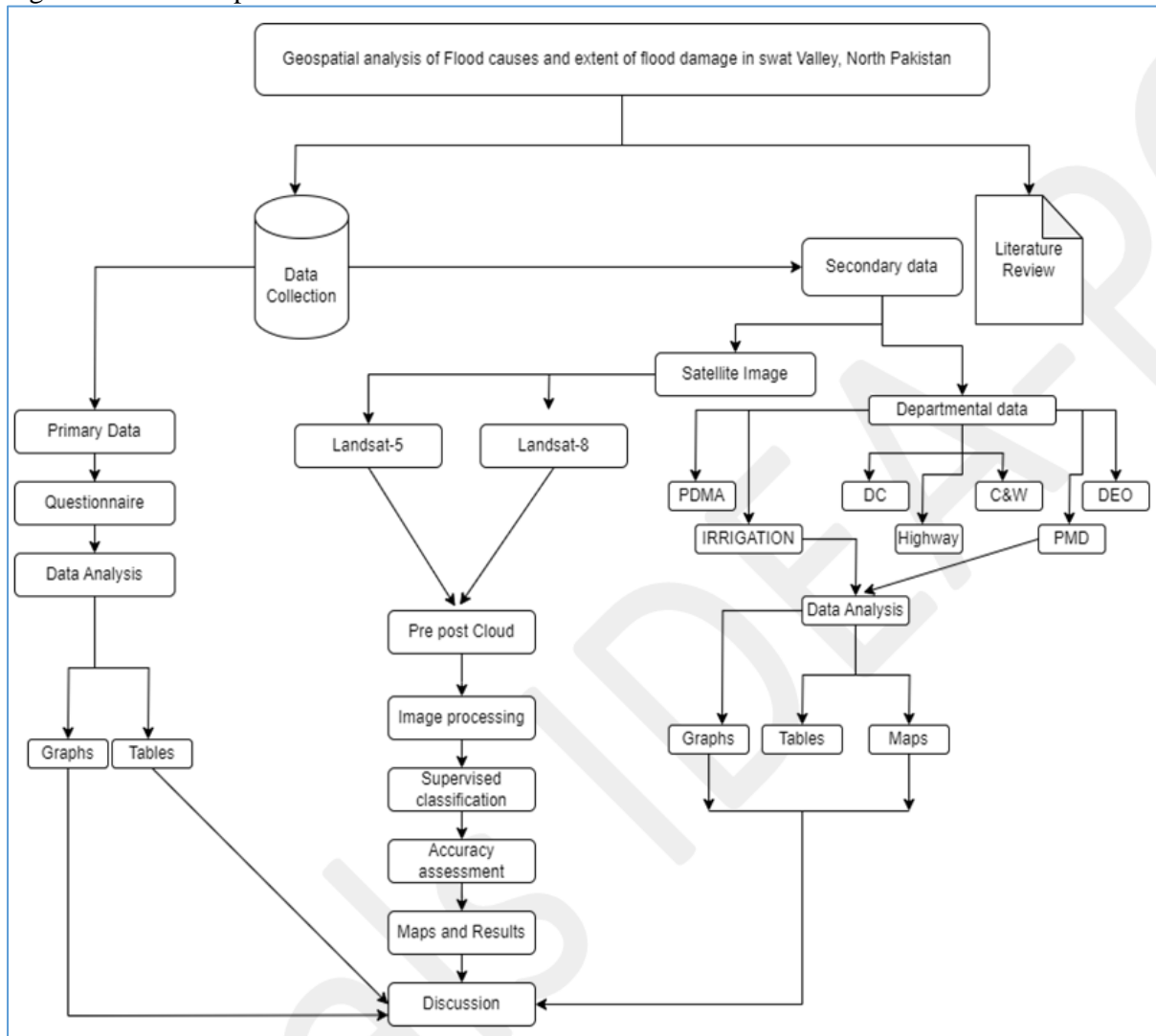
Floods occurred in district Swat in 2010, 2016, and 2020. Field visits were taken to investigate the causes and direct impacts of flooding in the study region. For detailed micro-level analysis, out of the total affected villages, two villages were selected from the Upper Swat floodplain and two villages from the Lower Swat floodplain. The selection of villages was based on the villages most affected by floods. Ningulai and Amamdherai were selected from the lower Swat floodplain, while Shagai and Paklai Shagram were chosen from the upper Swat floodplain. Sampling has many types; however, the random sampling approach is employed in the present research. Random sampling is the most fundamental form of sampling. A purposive sampling method was used, which is a type of non-probability sampling. 10% of the households were surveyed. From the four communities, a total of 133 questionnaires were filled, depending on the household size.

### **2.2.2. Secondary data acquisition**

From the United States Geological Survey (USGS) Earth Explorer, Landsat Satellite images of pre- and post-flood for 2010, 2016, and 2020 were downloaded. Secondary data was obtained from different relevant sources, such as data about bridge damage collected from the district Highway Authority Office Swat, school damage data from the District Education Office Swat and road infrastructure damage data from Communication and Works Office Swat. The Deputy Commissioner's Office of District Swat had collected data on house damage and human casualties which was also obtained by the researchers.

Global Positioning System (GPS) was applied to get the locations of damaged infrastructure. Those points were transferred to Google Earth, from where they were shifted to ArcGIS, which was displayed on the Swat union council map. Similarly, flood discharge data (1991–2020) of the River Swat was collected from the Irrigation Department Peshawar, whereas temperature and rainfall data (1989–2018) of Saidu, Kalam, and Malam Jabba were collected from the Pakistan Meteorological Department (PMD; Figure 2).

Figure 2: Research process



### 3. Results, analysis and discussion

This section deals with the main causative factors responsible for generating floods. Some of them are the rise in summer temperature, the practising of deforestation construction near the riverside, and heavy rainfall. Furthermore, it also includes the extent of damage to various sectors, such as the educational sector, bridges, houses, and human life. The last portion is about the pre-and post-flood scenarios, shown in the form of satellite images for 2010, 2016, and 2020.

#### 3.1. Causative factors of floods

A major part of Pakistan experiences an arid and semi-arid climate. It receives <250 mm of rainfall annually, while humid conditions prevail over a small area in the north (Haider & Adnan, 2014). Similarly, the highland climate prevails in the extreme north because of great heights. Like the rest of the country, the Khyber Pakhtunkhwa (KPK) province is also susceptible to floods because of its physiography and climate (Rahman & Khan, 2013). Here, floods are severe and recurrent extreme natural events. In the past eleven years, floods

happened in 2010, 2016, and 2020 in the district of Swat. The total number of villages affected by the flood in 2010 was 42, whereas 16 villages were affected in 2016 and 38 in 2020. In the 2016 flood, the total number of people who died was 13, while the injured was 13, and the total number of houses damaged was 99. In the 2020 flood, the total number of people who died was 13, while the number of injured was 16, and the total number of houses damaged was 53.

The analysis reveals that the physical and human factors played a role in the 2010 flood. Literature on hydro-meteorological extremes usually focuses on one variable, like precipitation or temperature. Similarly, there are studies on multi-variate types of events. The same is the case in the present study, where a complex combination of factors contributed to the severe flood in 2010. The investigation showed that prolonged, intense rainfall significantly contributed to this significant flood. Additionally, the Swat River's tributaries are facing severe flooding. In Swat River, recurrent floods occur yearly during August, June, and July (Rahman & Khan, 2011).

#### **3.1.1. Massive winter snow**

In 2010, heavy snow was recorded in the district of Swat at different meteorological stations. The analysis found that heavy snow was recorded at Kalam and Malam Jaba met stations in 2010, especially in January and February. This snow in the winter season later changed to heavy melting in the summer season, which was also considered a causative factor of this flood.

#### **3.1.2. High summer temperature**

Climate change is increasing in both magnitude and frequency (Shrestha & Lohpaisankrit, 2017). As a result, extreme weather events' frequency and intensity are immensely changing worldwide (Ali *et al.*, 2020). In the study area, floods are mainly induced by rainfall in the form of erratic and cloud bursts and summer snowmelt, especially in the late monsoon season, i.e. July to September (Rahman & Khan, 2011). Later on, this fast melting of snow results in floods and, as a result, causes damage to different sectors of life.

#### **3.1.3. Heavy rainfall**

In District Swat, a four-day wet spell (27–30 July 2010) occurred. The 2010 flood was caused mainly by this extended period of severe and persistent rain. Similarly, in 2016 and 2020, heavy rainfall was one of the causative factors of these floods in the Upper Swat. The natives believed thunderstorms were also a causative factor responsible for these floods in the Upper Swat.

#### **3.1.4. Rapid deforestation**

It is believed that forests mitigate flooding by serving as sponges, trapping water during periods of heavy rainfall and gently releasing it into streams, lessening the intensity of floods and maintaining stream flow during dry seasons (Taylor & Druckenmiller, 2022). Human activities, climate change, and poverty have led to increased deforestation. Deforestation presents multiple environmental problems in our society today. Flood is one of them (Oljirra, 2019). Deforestation affects flood frequency and severity. During the field survey, it was found that deforestation was also one of the factors affecting floods in the study area. The cause of rapid deforestation was the increased population and their demands.

### **3.1.5. Human encroachment onto the floodplains**

Similarly, floods are also intensified by several human factors, such as human encroachments over the channel limits, changes in land use and deforestation (Rahman & Khan, 2011). Due to the rapid population increase, people continuously encroach on the river. As a result, rivers' capacity decreases, and flood risk increases. The field study found that human encroachment towards rivers intensified flood characteristics in 2010, 2016, and 2020.

### **3.1.6. River discharge**

Most gauging stations in Pakistan, including Nowshera, Munda, Amandara, and Warsak were constructed during the British era. Discharge data for the previous thirty years of river Swat at Khwazakhela gauging station and Munda headworks was collected from the Irrigation Department, Peshawar. The discharge of the Swat River was exceptionally high because of glacier melting and four days of continuous rain from July 27-30. From the analysis, it can be seen that the 2010 flood caused destruction all over the study area. Analysis revealed that in District Swat during the year -2010, heavy and persistent rainfall occurred for about four days. Most of the meteorological stations recorded higher rainfall than the monthly average rainfall. This heavy rainfall has generated the highest peak discharge in River Swat. As a result, water overflowed its banks and caused high-scale damage to infrastructure, humans and livestock. It also damaged human settlements, schools, roads, bridges and agriculture.

This was the worst flood in District Swat, which caused disastrous damage to almost all sectors of life. The government's many weaknesses led to most of the destruction in the study area. Lack of structural and proper measures was also the leading cause of property damage. A range of causes contributed to the events that led to the disastrous floods of 2010 in the study area. Furthermore, June and July are among the hottest months of the year in the region, which worked as a driving factor behind the melting of snow. The monsoons are responsible for the majority of the rainfall in Pakistan from July to September. Originating in the Bay of Bengal, it flows northwest before reaching Pakistan. However, in 2010, the track of monsoon rains deviated from the regular flow pattern and proceeded towards the northwest and central parts of India. In 2010, the most significant recorded flow of the Swat River at the Khwazakhela gauging station was 175,546 Cusecs, while the discharge at Munda headwork was 350,000 Cusecs. The leading causes of the flood, which was recognised as prolonged rainfall and melting glaciers, were accountable for such hazardous floods in the district of Swat. According to the survey, the residents believe increased deforestation, urbanisation, and human encroachment along rivers are the reasons for floods in the district of Swat. Furthermore, according to people's perspective, the cause of the 2016 and 2020 floods were thunderstorms and excessive rainfall.

The hydrograph represents discharge data for the river Swat at Khwazakhela headwork from (1991–2020; irrigation department). This shows that the highest discharge of the river Swat was in 2010, followed by 1992, 1999, 1995, 2005, 2016, and 2020. Unprecedented rainfall combined with glacier melting resulted in a high discharge in 2010. In district Swat, the warmest months are June, July, and August, with average maximum temperatures exceeding 30°C. The Swat River's maximum recorded discharge at the Khwazakhela gauging station was 175,546 cusecs in 2010 (Figure 3). Because the river's discharge was excessive, floods occurred in the preceding years, resulting in the loss of lives, infrastructure and animals.

Figure 3: River Swat, mean annual discharge recorded at Khwazakhela 1991-2020

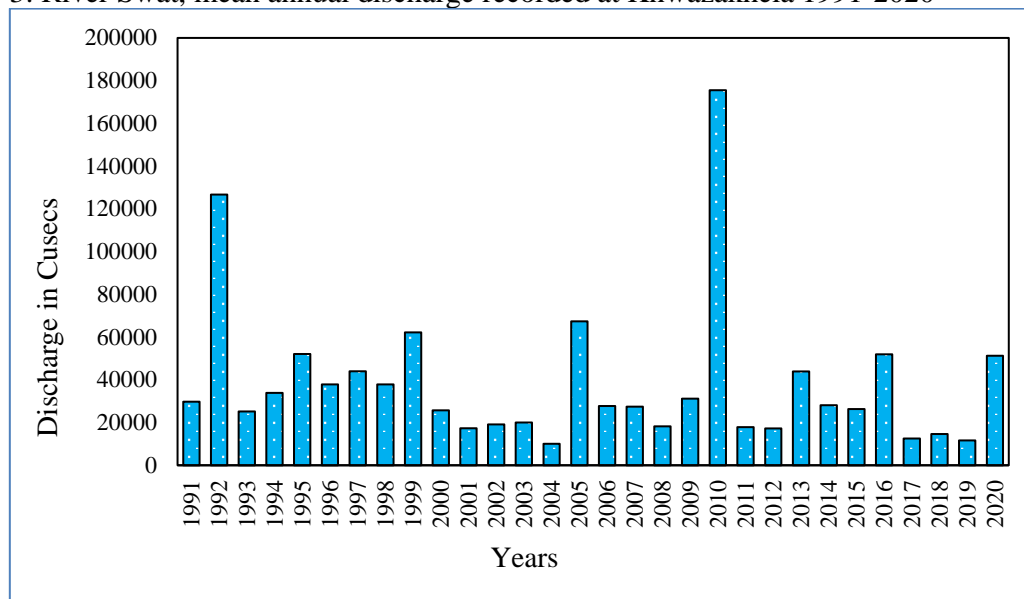
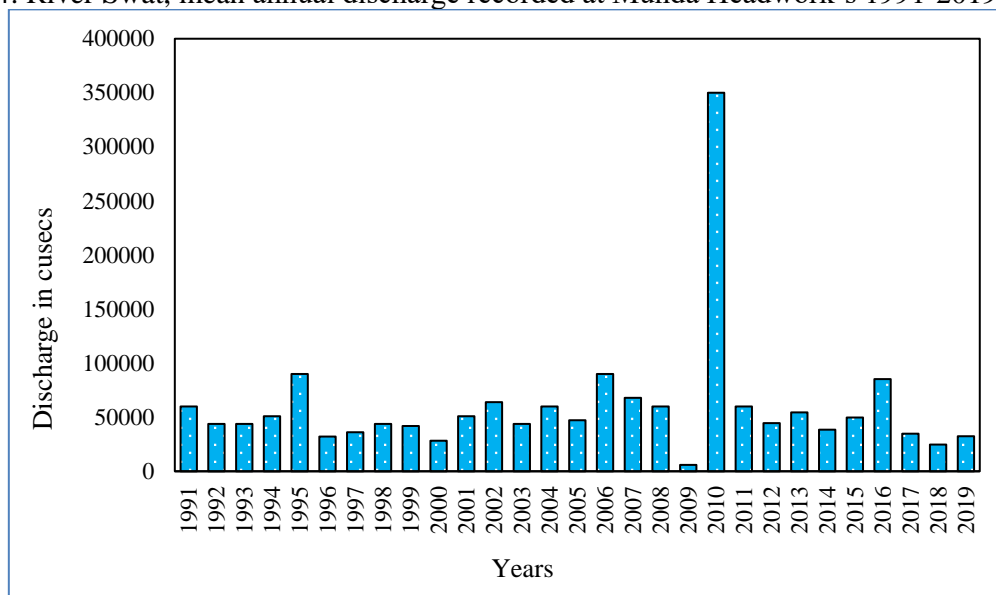


Figure 4 represents discharge data for the river Swat at Khwazakhela. The graph illustrates the Swat River's discharge data. It can be seen clearly that in 2010, the flow of the River Swat at Munda headwork was very high, at about 35,0000 cusecs, which was one of the causes of the 2010 disastrous flood. Prolonged rain and glacier melting were the fundamental causes of this high outflow. Furthermore, it can be seen that the discharge rate was high in some other years, and floods occurred in those years as well. Among them are the 1995 and 2016 floods. Rainfall during the summer monsoon season can directly affect river discharge.

Figure 4: River Swat, mean annual discharge recorded at Munda Headwork's 1991-2019



Respondents' perceptions of flood causes were different. The majority of people view Prolonged rainfall, glacier melting, and deforestation as the main causes of floods. The analysis revealed that the 2010 flood damaged infrastructure, including houses, roads, bridges, schools, and hospitals. Schools were also severely damaged by this devastating flood.

### 3.2. Extent of flood damages

#### 3.2.1. Educational sector damages (Floods-2010)

##### A. Flood 2010 damages to boy's schools

The 2010 flood destroyed about 25 boys' institutions, including primary, secondary, and high schools (Education District office). All the boys' schools listed were destroyed, causing a significant loss to the education sector (Figure 5). Most of the schools are located near the river, implying that this riverine flood caused widespread damage (Tables-1 and 2).

Figure 5: District Swat, boys schools damaged in 2010 flood

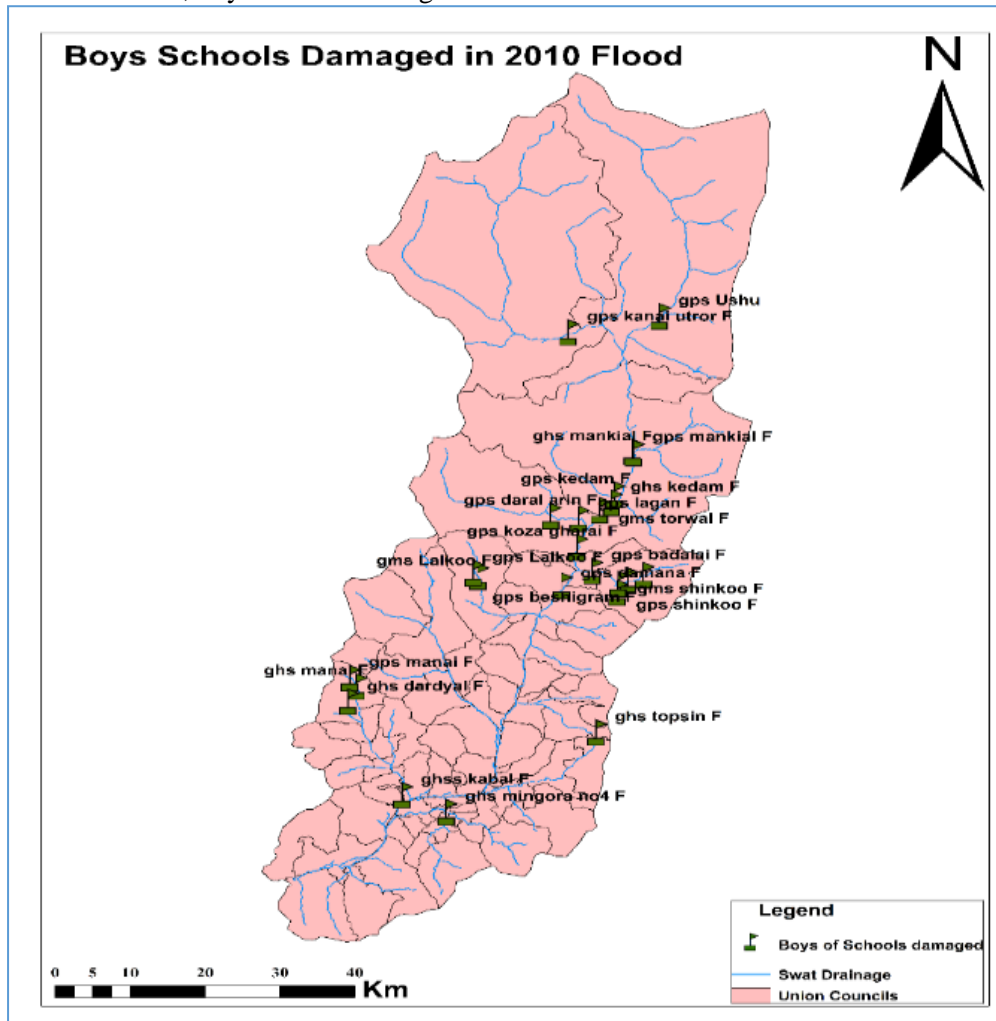


Table-1: District Swat, the extent of flood damages to government schools for boys

S. No	Union Council	Extent of Damages	No. of Boys Schools
1	Bahrain	Fully	18
2	Kabal	Fully	4
3	Matta	Fully	1
4	Khawazakhaila	Fully	1
5	Babuzai	Fully	1

## B. Flood 2010 damages to girls' schools

In the flood of 2010, the total number of girls' schools affected was 17. Seven schools were partially damaged, while ten others were completely devastated (Figure 6). Educational institutions were severely impacted (Table-2; Communication & Works).

Figure 6: District Swat, girls schools damaged in 2010 flood

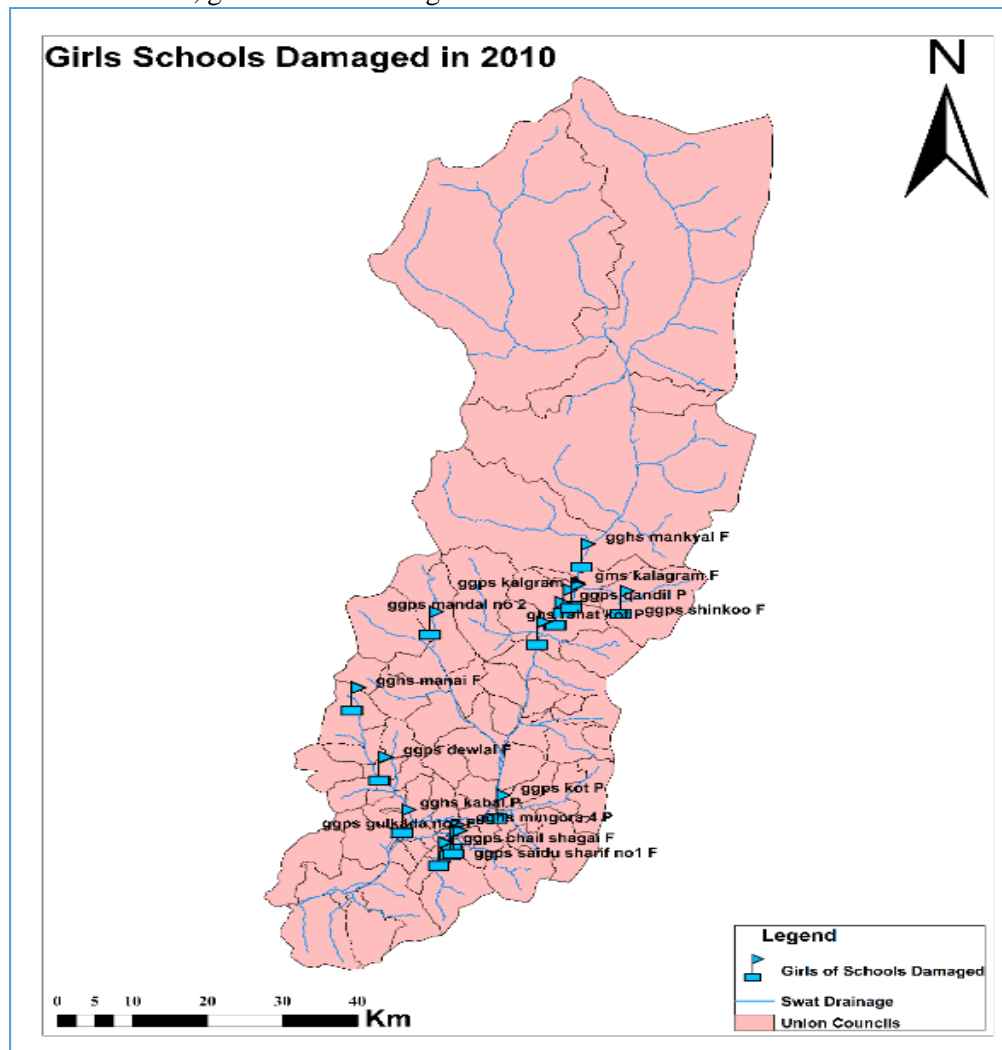


Table-2: District Swat, extent of flood damages to government schools for girls

S.No	Tehsil	Extent of Damages	
		Partial	Complete
1	Bahrain	3	-
2	Bahrain	-	4
3	Babuzai	1	-
4	Babuzai	-	3
5	Charbagh	1	-
6	Khawazakhaila	1	-
7	Khawazakhaila	-	2
8	Matta	1	-
9	Matta	-	1

### C. Flood 2020 damages to boy's schools

In 2020, a flood came, wreaking havoc on many aspects of society. During the floods of 2020, 12 schools were inundated. One school was partially damaged, while the remaining eleven were completely demolished (Table-3). The map indicates that some of the school's damage in the flood of 2020 was located close to the river, while others were located a far distance from the river, which is evidence that this was a flash flood that caused destruction. Furthermore, people in the Upper Swat thought extreme and prolonged rainfall, along with thunderstorms, were responsible for this flood (Figure 7).

Figure 7: District Swat, boys schools damages in 2020 Flood

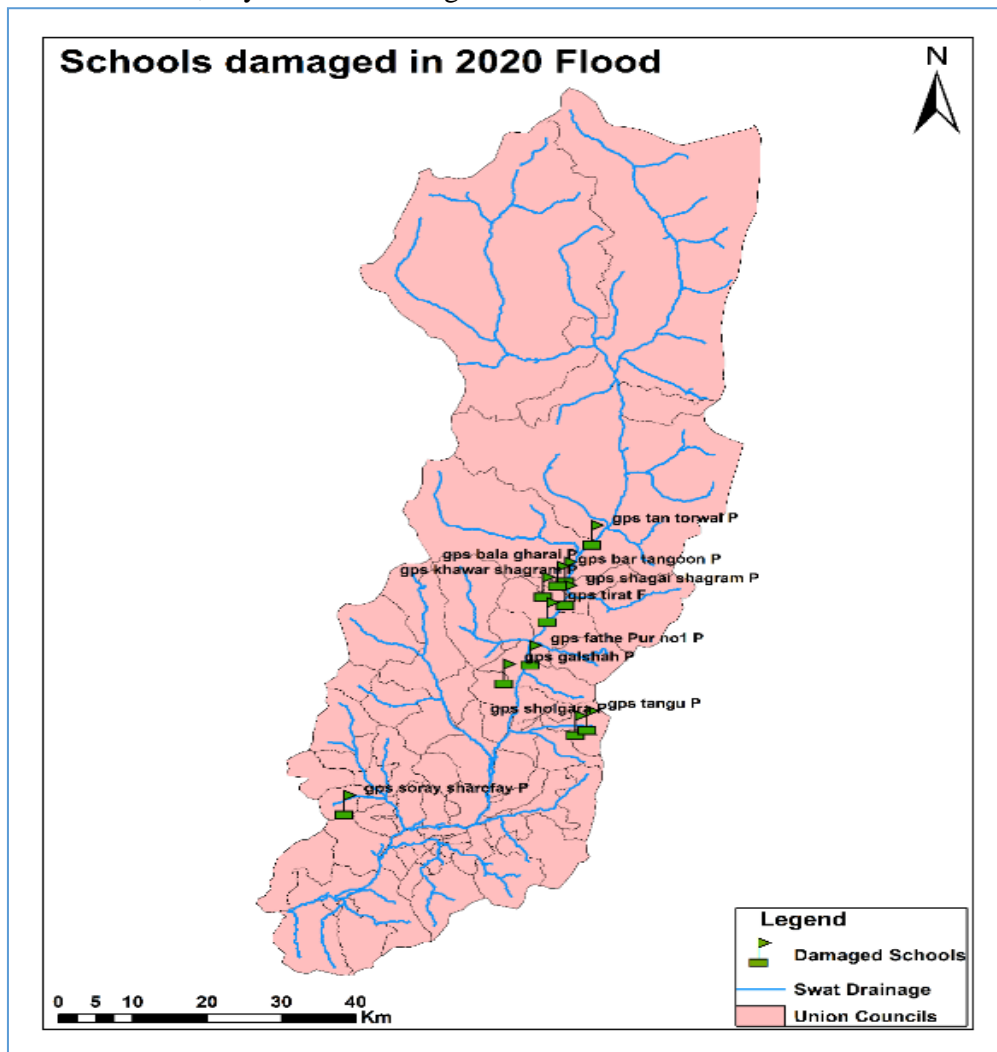


Table-3: District Swat, the extent of 2020 flood damages to govt schools for boys

S.No	Tehsil	No. of Schools	Extent of Damages	
			Partially	Completely
1	Bahrain	7	Partially	
2	Matta	3	Partially	
3	Kabal	1	Partially	
4	Khwazakhaila	1	Partially	

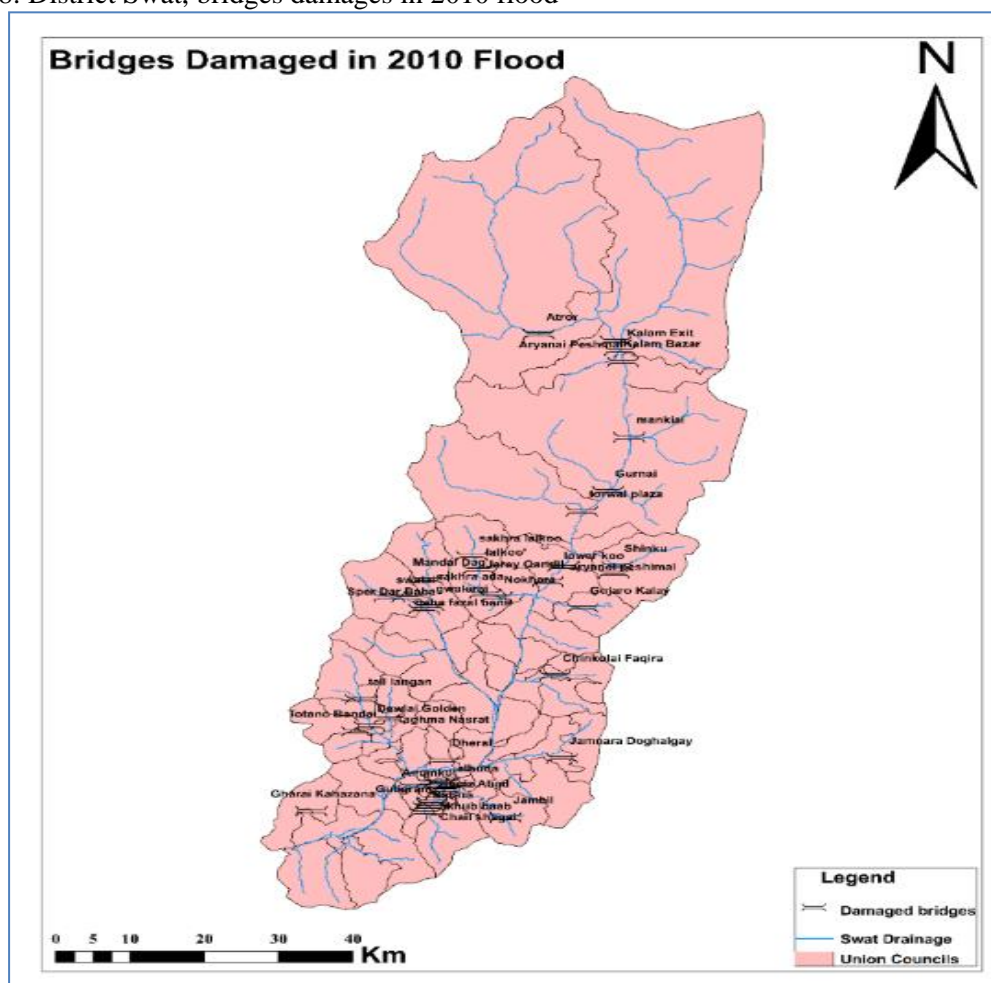
### 3.2.2. Damages to bridges

Figure 8 shows that the flood of 2010 caused huge damage to infrastructure, including bridges and roads. A total of 41 bridges were damaged during the 2010 flood in District Swat (Table-4). The bridges in both the Upper and Lower Swat were damaged. According to the resultant analysis, the most significant recorded discharge, low bridge height, intense flow energy at bridging sites, tree logs, and lumber have harmed all these structures. These bridges were helpful for the people in the study area. People suffered greatly because of the flood and faced several challenges. In Upper Swat Qandil, near Fathepur, a flood cut the road. People in the Upper Swat were trapped on the upper side, while those in the Lower Swat were trapped on the lower side. A survey was started to restore the bridges. Foreign countries donated steel bridges to the Pakistan army. The flood had a considerable economic impact on the study area.

Table-4: District Swat, the extent of flood damages to bridges during the 2010 flood

S.No	Tehsil	No of Bridges Damaged
1	Kabal	6
2	Bahrain	13
3	Matta	9
4	Babuzai	10
5	Barikot	2
6	Khwazakhaila	1

Figure 8: District Swat, bridges damages in 2010 flood



### 3.2.3. Damages to bridges (Flood 2020)

Figure 9 shows that bridges were also devastated during the flood of 2020. Seven bridges were destroyed, most in Bahrain tehsil, and one in Babuzai tehsil of district Swat. In Bahrain, two roads, one in Union Council Tirat and the other in UC Bashigram, were destroyed, which caused the residents of these areas to face difficulties and hurdles (Tables-5 & 6; District Swat Highway Authority).

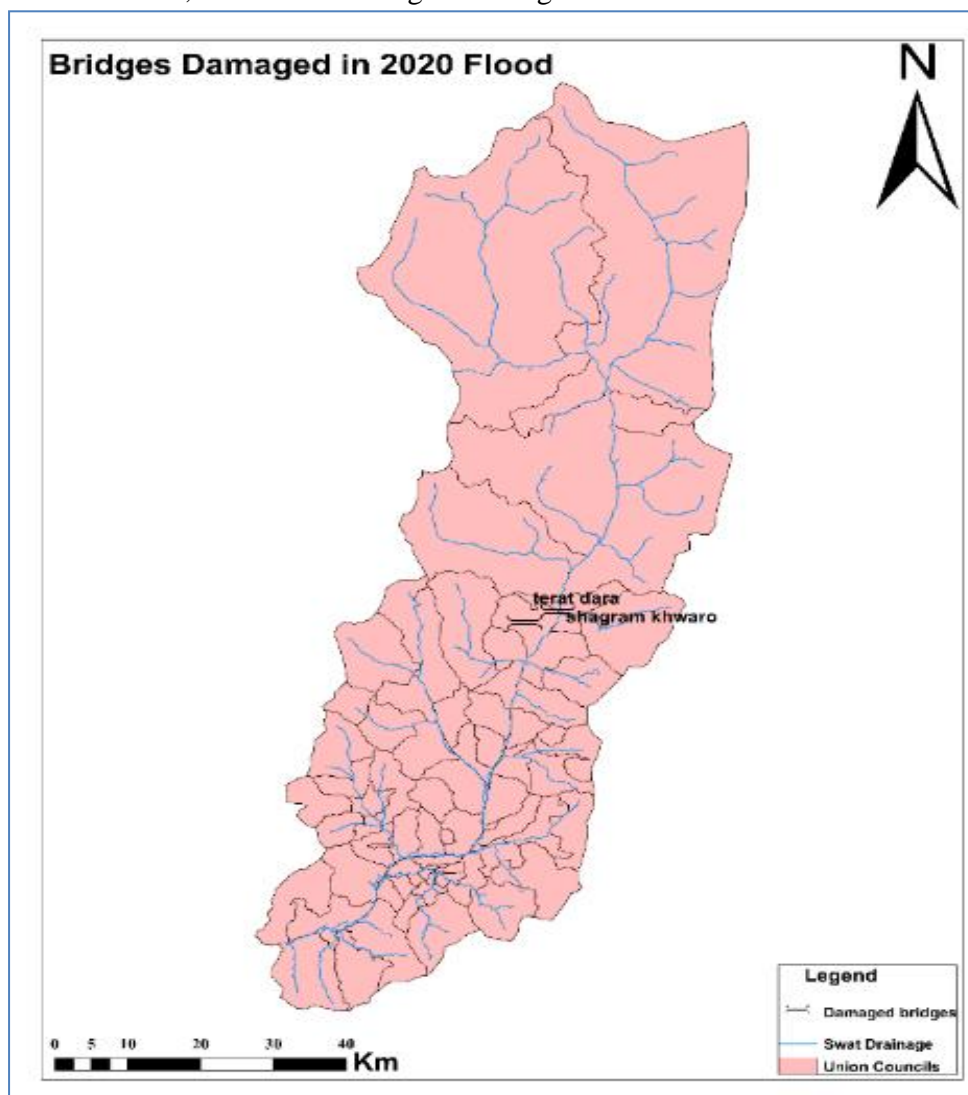
Table-5: District Swat, extent of 2020 flood damages to bridges

S.No	Tehsil	No of Bridges
1	Bahrain	6
2	Mangalore	1

Table-6: District Swat, extent of 2020 flood damages to roads

S.No	UC	No. of Road
1	Tirat	1
2	Bashigram	1

Figure 9: District Swat, 2020 flood damages to bridges



### 3.2.4. Flood 2020: Death tolls

Floods have put human and animal lives at risk, resulting in fatalities. Most of the casualties in the 2020 flood occurred in the Upper Swat of tehsil Bahrain, particularly in Shagram and Tirat Dara, and some in Matta (Figure 10). In the flood of 2020, 10 people died in Bahrain, 3 people in Matta and 16 were wounded. This flood was caused by heavy rains that caused flash floods in the Upper Swat, mainly in Bahrain (Table-7; Deputy Commissioner Office). According to the local residents and government officials, heavy rainfall throughout the night was the cause of the flood.

Table-7: District Swat, list of casualties in 2020 flood

S.No	Name of Tehsil	No. of people died
1	Matta	3
2	Bahrain	10

### 3.2.5. Flood 2020: Damages to houses

Floods wreak havoc on people's lives as well as their possessions. Several properties were damaged during the 2020 flood in the tehsil of Bahrain (Figure 11). About 56 houses were damaged, some of which were destroyed partially, while others were destroyed entirely. They barely managed to preserve their lives due to the sudden flood.

Figure 10: District Swat, 2020 flood tolls

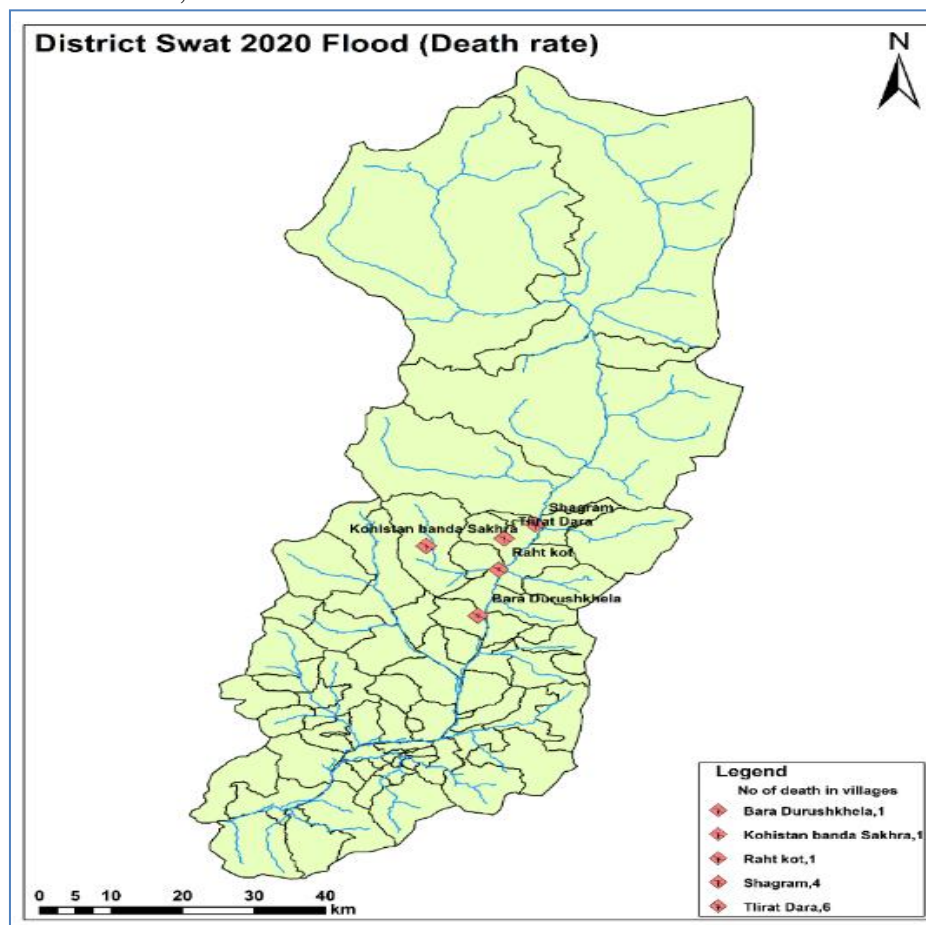
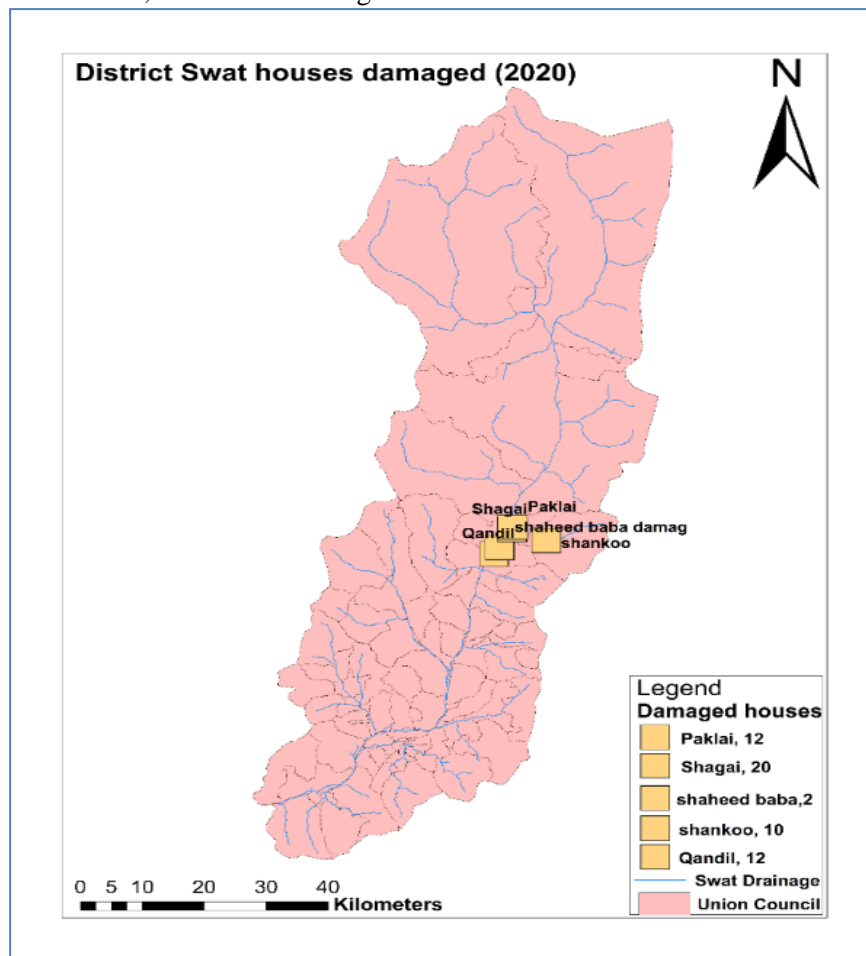


Figure 11: District Swat, 2020 flood damages to houses



### 3.2.6. Flood 2016: Damages to houses

Floods struck in 2016, causing havoc in Bahrain and damage in other Swat tehsils. A total of 99 houses were damaged, 63 of which were partially damaged, while 36 were fully destroyed. This flood claimed the lives of 13 individuals and wounded another 13 (Table-8; PDMA). People and government officials alike believed this flash flood caused infrastructure damage and resulted in human casualties.

Table-8: District Swat, extent of flood 2016 damages to houses

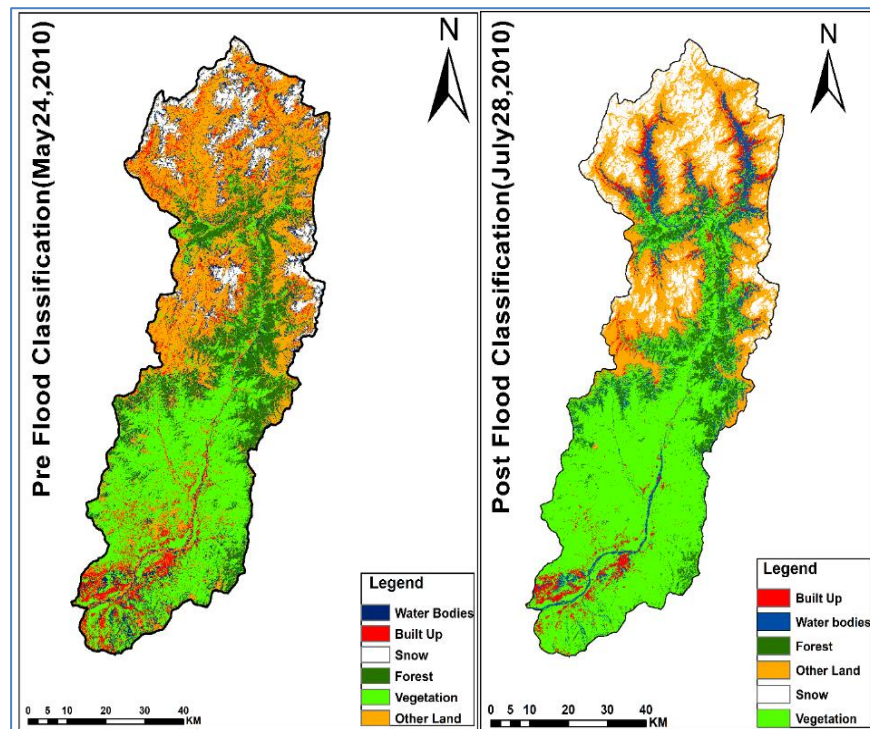
S.No	Damage Category		Place
	No of Fully damaged houses	No of Partially damaged houses	
1	36 Fully	63 Partially	Bahrain

### 3.3. Land use land cover comparison of 2010 pre-post flood images

The image was classified into six classes, which include forest, vegetation, built-up areas, other land, water bodies, and snow (Figure 12). The Landsat image of 24<sup>th</sup> May was used to analyse Pre-food situation, and 28<sup>th</sup> July image was used for Post-food situation in the study area. The classification of the flood image of May 24, 2010, shows that water covered 6% of the area while barren land, vegetation, snow, forest and built-up areas were covered by 33%, 34%, 12%, 10%, and 5%, respectively. Similarly, the classification of the post-flood image of 28<sup>th</sup> July

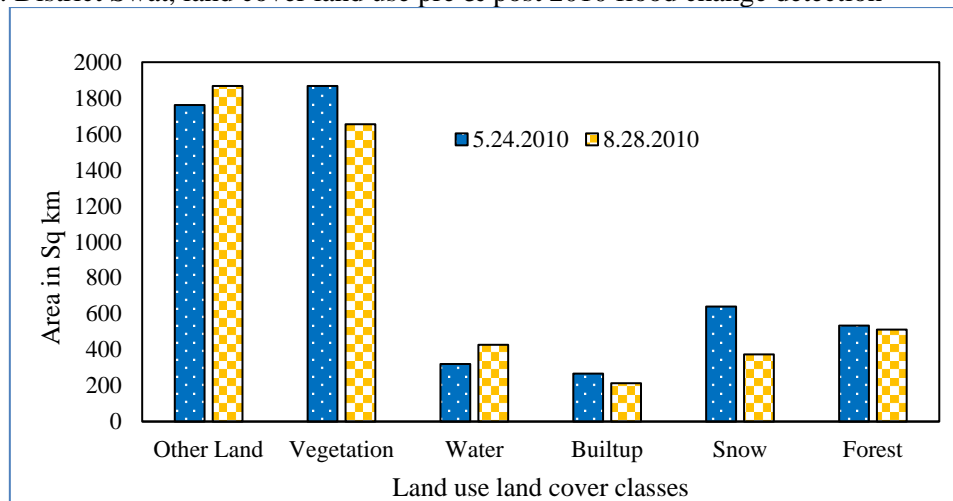
2010, shows that 9% of the area was covered by water while barren land, vegetation, snow, forest, and built-up areas were covered by 37%, 33%, 7%, 10%, and 4%, respectively.

Figure 12: District Swat, pre-post flood land cover land use changes



The post-flood change detection investigation reveals a significant shift in water class, with an increase of 3%, from 6% to 9%, while the built-up area has reduced by 1%, from 5% to 4%. The barren land increased by 4%, from 37% to 33%. The vegetation rose by 1%, from 34% in the pre-flood scenario to 33% in the post-flood scenario. The snowfall reduced from 12% to 7 (Figure 12). In pre, floodwater was less, which rose in post-flood conditions. The built-up area was reduced in the flood situation (Figure 13). In 2010, peak discharge was above 350,000 cusecs at the Munda headworks, River Swat, which caused severe damage. This disastrous flood severely damaged schools, houses and the agriculture sector.

Figure 13: District Swat, land cover land use pre & post 2010 flood change detection



### 3.4. Land use land cover comparison of 2016 pre-post flood images

The Landsat ETM image from 21<sup>st</sup> March 2016 was classified as a pre-flood condition. However, the image of 8<sup>th</sup> May 2016 was assigned for the post-flood 2016 instance analysis. The pre-flood image classification on March 21<sup>st</sup>, 2016, reveals that water covered 1% of the region while barren land, vegetation, snow, forest, and built-up areas were covered by 24%, 9%, 55%, 6%, and 5%, respectively. Likewise, the post-flood image classification of May 8, 2016, shows that 3% of the area was covered by water, while barren land, vegetation, snow, forest and built-up areas were covered by 33%, 16%, 38%, 5% and 5% respectively (Figure 14). The vegetation in post-flood was decreased. Likely, the forest cover in post-flood was reduced (Figure 15).

Figure 14: District Swat, pre-post flood land cover land use changes

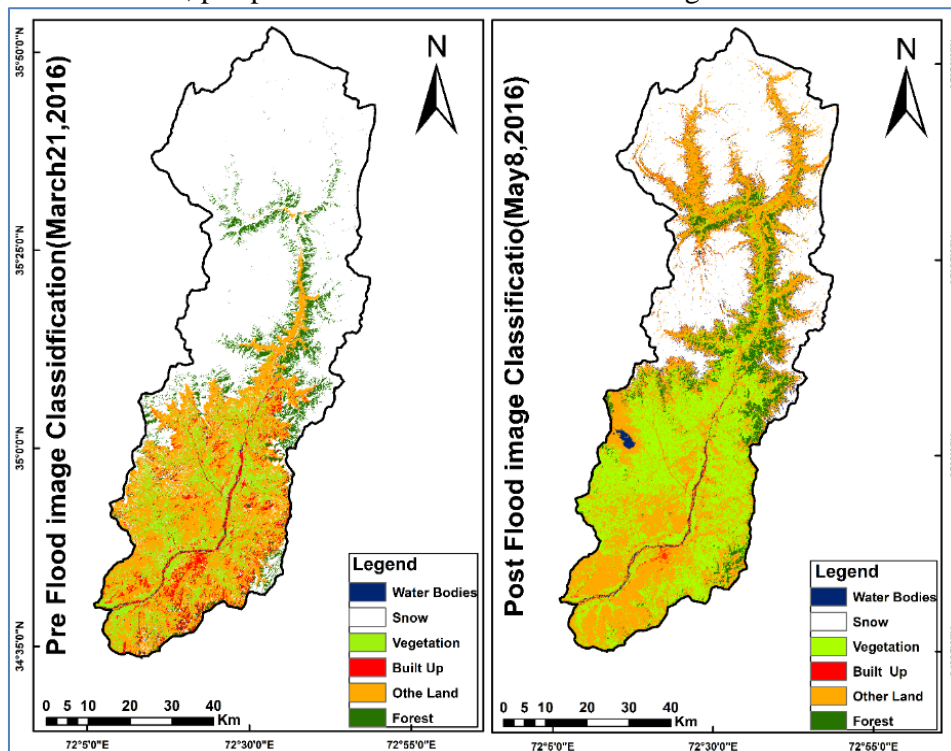
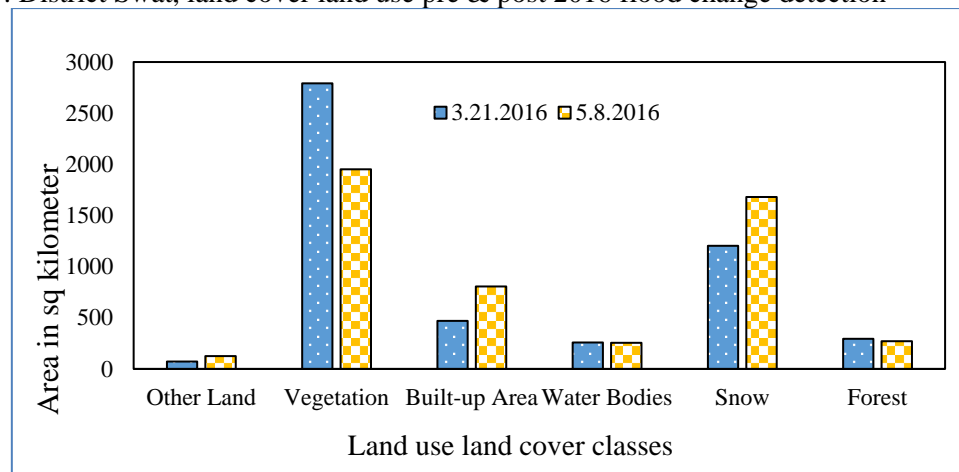


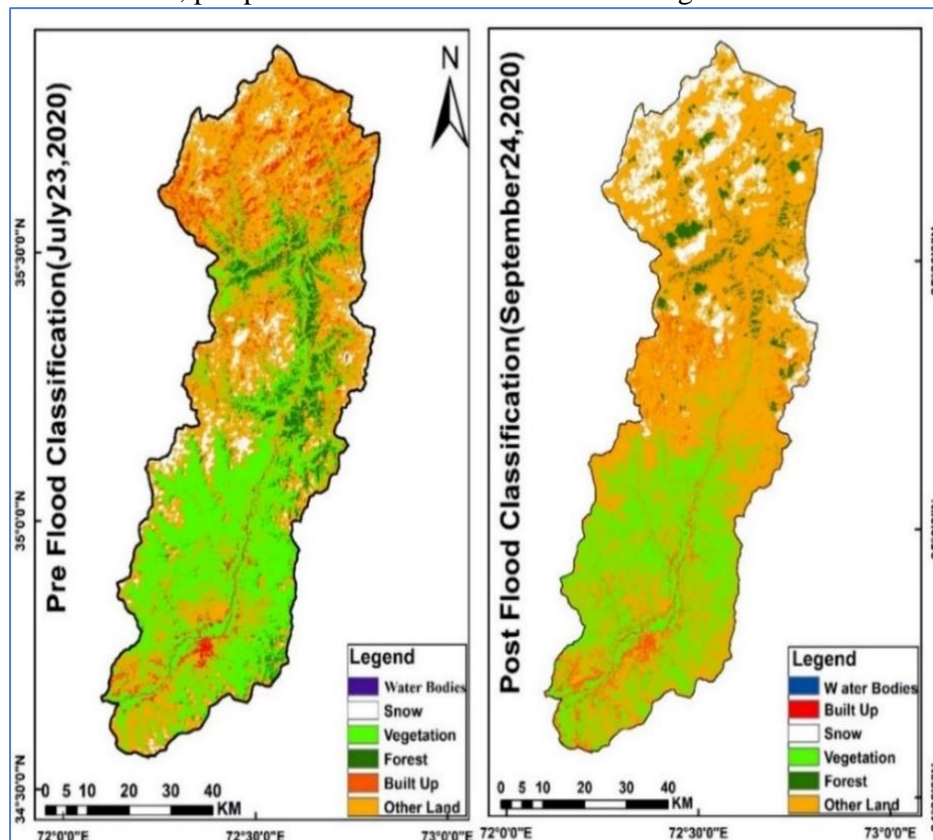
Figure 15: District Swat, land cover land use pre & post 2016 flood change detection



### 3.5. Land use land cover comparison of 2020 pre-post flood images

The land cover in District Swat is shown as a percentage and per kilometre in the pre-and-post floods images. The images were downloaded for the pre-and-post flood situation and then classified to find out the situation. The images were classified into six classes, which include water bodies, other land, vegetation, built-up, forest, and snow (Figure 16). The Landsat ETM image of the 23<sup>rd</sup> of July 2020 was categorised for a pre-flood condition, whereas the image of the 24<sup>th</sup> of September 2020 was categorised for post-flood instance analysis and classification in District Swat.

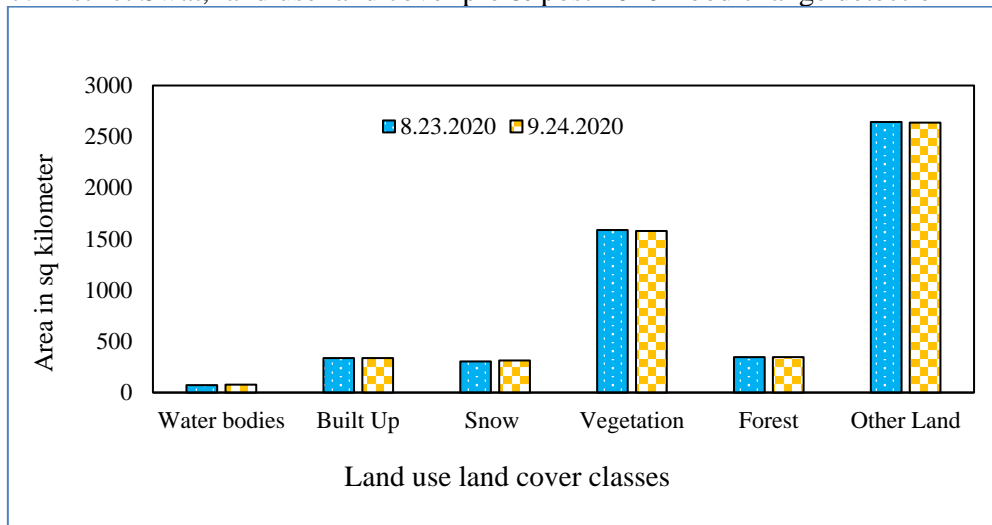
Figure 16: District Swat, pre-post flood land use land cover changes



The analysis of the classification in the downloaded images given the bar chart revealed that in the pre-flood situation, the largest area of 2792 square kilometres, representing 55%, was occupied by snow, then reduced to 1952 square kilometres, representing 38% of snow in the District Swat. Likely, the built-up area was 258 km<sup>2</sup>, which was reduced to 256 km<sup>2</sup> after the flood of 2020 (Figure 17).

Furthermore, other land was 1204 square kilometres, representing 24%, was occupied by other land in the pre-flood situation, which was then increased to 1681 square kilometres, representing 33% of other land. Other land was increased because when snow melted after the post-flood situation, it also appeared in the category of other land, which in the pre-flood situation was occupied by snow. The water bodies covered 72 km<sup>2</sup>, representing 1% of the area occupied by water bodies, which was increased to 125 km<sup>2</sup>, and representing 3% of the water bodies (Figure 16).

Figure 17: District Swat, land use land cover pre &amp; post 2020 flood change detection



#### 4. Conclusion

The research area district of Swat is located in Khyber Pakhtunkhwa province, northern Pakistan. It is susceptible to flooding and the resulting damage. The study area's most affected sites were Ninguwali, Amandarai, Paklai and Shagai. These villages were particularly affected due to their proximity to the river. In the research region, infrastructure such as bridges, buildings, water supply schemes, irrigation canals, retaining walls, and roads were severely damaged, especially in the selected villages. Flooding is caused by prolonged rainfall, glacier melt, and cloud bursts. Every year, a massive number of deaths occur as a result of these devastating flash floods. Floods are most common in the late monsoon season, from July to September. Pakistan is prone to various climate-related calamities, including heat waves, droughts, floods, and other extreme weather events. It arises in the Bay of Bengal and proceeds northwest until it reaches Pakistan. However, in 2010, the track of monsoon rains deviated from the regular flow pattern and proceeded towards the northwest and central parts of India. Several factors were responsible for it, such as poverty and construction near the river. According to the analysis, Swat is a hilly region due to the existence of rivers. Flooding has been highly hazardous to human and animal lives, resulting in human injuries and fatalities. From the analysis, it can be seen that the 2010 flood caused destruction all over the study area. Crops and the agriculture sector were also harmed.

According to the findings, the research area's physical and economic infrastructure was severely destroyed by floods in 2010. It was also found that in the 2010 flood, most of the damage that occurred to infrastructures was mostly near rivers, which means that it was a riverine flood. It was also known that in the 2020 flood, some damages occurred near the river and others away from it, indicating that it was a flash flood. The study also discovered that people encroaching on riverbanks significantly increased the frequency of floods in the Swat district. In 2016 and 2020, flash floods mainly affected Upper Swat. The water flow in 2020 was very rapid and washed away the infrastructure with it. It is susceptible to flooding, which results in widespread damage. The analysis of 2010 images found that dramatic change occurs in water bodies' class. Water bodies in pre-flood was 6%, which increased to 9% in post-flood. The built-up area in pre-flood was reduced from 5% to 4% in post-flood analysis. Snow decreased in pre-flood from 12% to 7% in post-flood analysis. Vegetation was reduced in pre-

flood from 34% to 33% in post-flood analysis. From the 2016 analysis, it was found that water bodies in pre-flood was 1%, which was raised to 3% in post-flood. Snow in pre-flood was 55%, which reduced to 38% in post-flood. Forest was reduced in post-flood to 5% from 6% in pre-flood analysis. In the post-flood of 2020, no apparent change was observed except in the barren class; barren land was decreased from 50% to 30%, while vegetation was raised from 30% in the pre-flood case to 50% in the post-flood condition. It was found that 2010 was the worst flood in the past eleven years. This flood affects both upper and lower Swat. The research also discovered that the majority of the communities were vulnerable to floods due to poverty, the construction of houses near rivers, and the building materials used. It was also concluded that the study area does not have proper mitigation measures.

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