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Swiss Agency for Development and Cooperation SDC

Event Analysis
2022 Floods in Swat Valley, Pakistan
Synthesis Report

Acronyms

DRR	Disaster risk reduction
FDFA	Swiss Federal Department of Foreign Affairs
FOCP	Swiss Federal Office for Civil Protection
FOEN	Swiss Federal Office for the Environment
GIS	Geographic information system
GLOF	Glacial lake outburst flood
IRM	Integrated risk management
NDMA	National Disaster Management Authority
PDMA	Provincial Disaster Management Authority
SDC	Swiss Agency for Development and Cooperation
SHA	Swiss Humanitarian Aid
SFM	Sustainable forest management
UAV	Unmanned aerial vehicle (Drone)

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The 2022 Floods Event Analysis was mandated by the Swiss Agency for Development and Cooperation (SDC) in collaboration with the Swiss Federal Office for the Environment (FOEN). This report contains the experts' findings, conclusions and recommendations.

Acknowledgement
The authors would like to thank the authorities, organisations, experts and the many individuals who supported the 2022 Floods Event Analysis for their great collaboration. In particular the National Disaster Management Authority of Pakistan (NDMA), the Provincial Disaster Management Authority of Khyber Pakhtunkhwa (PDMA), the Swiss Embassy in Islamabad, the Swiss Agency for Development and Cooperation SDC, the Swiss Federal Office for the Environment FOEN; Khursheed Ahmed, Sami Ullah and Sajjad Ali Khan of the local support team and Dr. Mohammad Shafique and his team of the University of Peshawar.

Content

1. Executive summary

Pakistan experienced heavy rains and extended floods during the monsoon season 2022, which caused great damage, especially in Swat Valley, in the Khyber Pakhtunkhwa province of Pakistan. Switzerland reacted immediately to Pakistan's international appeal for assistance on 26 August 2022 and deployed a rapid response team from the Swiss Humanitarian Aid Unit (SHA) followed by a Swiss Agency for Development and Cooperation (SDC) self-implemented project (direct action) focusing on the affected areas of Swat Valley. After three months of operation, with the support of SHA and local specialists, 11 schools and 16 water distribution systems had been repaired and 8 suspension bridges built, which helped to restore the valley's residents' access to local markets and enabled the children to return to school. Over 33,000 people in Swat Valley benefited from this immediate assistance.

Swat Valley faces recurrent floods. Drawing lessons from the devastating floods in 2022 is important for building back better and reducing disaster risk in Swat Valley. Therefore, Switzerland proposed to the Islamic Republic of Pakistan to undertake a Flood Event Analysis and invited the National and Provincial Disaster Management Authorities (NDMA, PDMA) and the National Centre of Excellence in Geology of the University of Peshawar to collaborate in the study. The study was conducted under the leadership of the SDC in collaboration with the Swiss Federal Office for the Environment (FOEN).

The study is based on the integrated risk management (IRM) concept. It includes on-site field observations supported by spatial data analysis, including debris flow calculations, flood plain as well as risk map modelling based on satellite and UAV-based aerial survey (drone) images. During the preparatory mission in Pakistan of May 2023, contacts were established with the authorities at all administrative levels. The main mission and all fieldwork in Swat Valley took place from 30 May to 18 June 2023.

Findings presented here are the result of the information gathered during the two missions in Pakistan, including the spatial data analyses:

1. **The massive floods that occurred in 2010 had a great influence on the 2022 floods.** During the last century, there was only one major flood registered in 1929. Since then, people have occupied the actual river area, living and farming there. In 2010, the river reclaimed its traditional bed and the flood of 2022 took place largely in the wider river area of 2010.
2. **The 2022 event started off in the north** of Swat Valley and was caused by several days of persistent and heavy rainfalls distributed over the catchment area (22–26 August).
3. **Debris flows from the tributaries were responsible for high sediment transport** and a considerable part of the debris was transported into the main river.
4. **Debris flows dammed the Swat river at different places and caused double damage effects:**
   First, a lake was formed upstream of the dam and sediments were deposited. The water level rose significantly, flooding settlements and fields.
   Second, after the dam broke, the river eroded bed and banks downstream and deposited the material again. Settlements and roads were destroyed through the bank failures and where material was deposited.
5. **The very high sediment transport led in many places to significant deposits and riverbed aggradation.** The 2010 event had already led to massive riverbed elevation. In some places like Kalam and Bahrain, the riverbed is now at the same level as houses and roads.
6. **Bank erosion was massive in places and led to major damage.** Buildings were scoured and undercut or dragged into the river by sliding embankments.
7. **Landslides did not play an important part.**
8. **Glacial lake outburst floods (GLOFs)** were not registered. All mountain lakes in the area still exist. But the risk of GLOFs is still there.

9. **A high percentage of damage was due to the spatial human-nature conflict.** Before 2010, there were already numerous buildings within the riverbed, which had been washed away at that time, but rebuilt later. Also, after the floods of 2022, buildings are rebuilt on the same site. This was despite the fact that there has been a law in place since 2002 which prohibits building near the river.
10. **Residual risk is very high.** The residual risk after the events of 2022 is very high in several places. Due to the rise of the riverbed, less runoff than before can now lead to flooding of settlements and critical infrastructure. Also the banks have eroded dangerously close to many buildings. It is only a matter of time until the river undermines these buildings, causing them to collapse.
11. **Degradation of landscape and forest was observed**. Local overuse of the forests and the lack of forest rejuvenation is a major factor of degradation. It is estimated that the landscape south of Bahrain has recovered locally, and north of it has degraded.
12. **Previous projects have shown a beneficial effect so far.** Previous projects of the forest department of Pakistan and the SDC have been effective and the small stabilising constructions in small gullies survived the event of 2022. Local reforestation measures have also been successful and have had a positive effect on surface erosion processes.

In conclusion, it can be said that without the 2010 floods, the 2022 floods would have been different in terms of their evolution, morphological behaviour and the damage they caused. The 2022 event was too big to be brought under control by humans. Such major events cannot be mitigated or prevented by technical measures.

A succession of different processes caused damage throughout the valley. The damage in 2022 was not caused by a single triggering event, but by a number of processes that complemented and interacted with each other to produce the damage. After the event, the potential risk of damage has increased in many places in comparison to before 2022. The risk of future damage is very high, especially on river stretches with extreme deposits and bank erosion.

The event clearly showed the spatial conflict between humans and nature, and it looks like this effect will intensify in the future. In recent years, the population of Swat Valley has increased and with it the pressure to settle in high-risk areas.

More damage must be feared in future. Due to the fact that also minor discharges, as a result of riverbed aggradation, and thus a higher frequency of flooding are to be feared, damage will occur more frequently and, in some cases, more intensively.

Based on the facts gathered in the short time of the study, no direct evidence of climate change was found. The available data from Chaktara and Khwazakhela do not indicate significant changes in the discharge regime of the Swat river. The mere fact that two major events take place in a short space of time after a long period of time does not contradict the statistical findings. But data are insufficient to make a direct comparison between the two major events of 2010 and 2022. In addition, potential trigger conditions such as rainfall clusters, the possible influence of melting permafrost or the formation of debris flows in the retreat area of glaciers could not be investigated and need more attention in the future.

For detailed research, data is lacking. Reliable data for the event analysis were often not available, either because the measuring stations were not in operation or because they are non-existent.

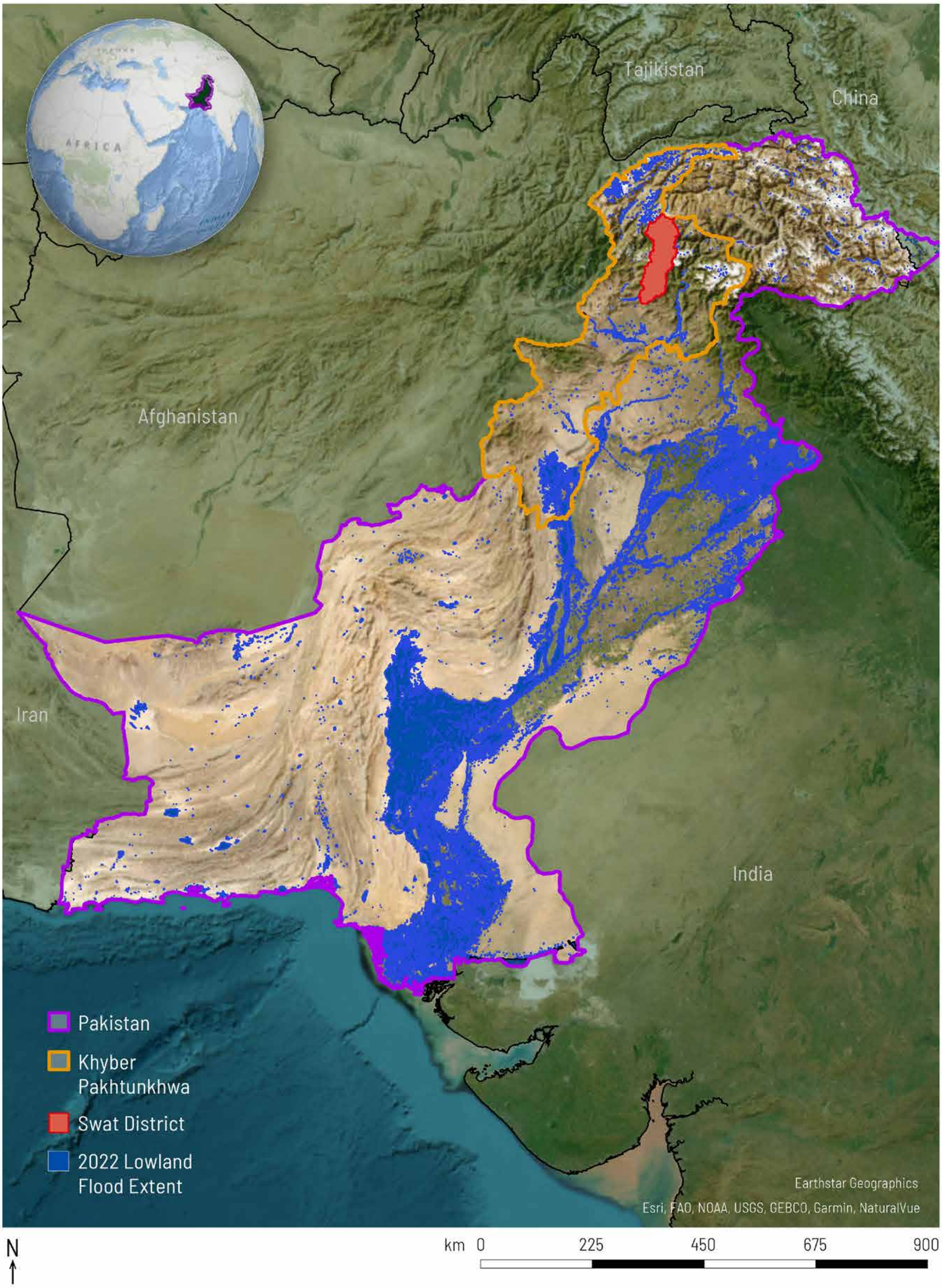


Fig 2-1 Overview of Flood Event 2022. Map: P. Walther. Data: UNOSAT (flood extent), OCHA (administrative boundaries), ESRI Basemap

2. Introduction

The overall goal of the Flood 2022 Event Analysis is to support the protection against flood risk of the population of Swat Valley, in Khyber Pakhtunkhwa Province, Pakistan. The flood event analysis serves as a basis for the definition of disaster risk reduction (DRR) measures and is based on the concept of integrated risk management (IRM). The NDMA and PDMA also work according to the IRM concept.

The study has the objective to provide an overview of key events and damage in the Swat Valley. It describes how events unfolded and provides an overview of residual risks and recommended DRR measures.

Swat Valley and the flood of 2022

Swat Valley
Area covered by the study: 5400 km² (Fig. 2-1). This is roughly the size of the canton of Valais in Switzerland.
Population: 2.3 million (canton of Valais 350,000).
Swat is a mountainous region with peaks of almost 6000 m asl. (Fig. 2-2a)
The Swat river forms at Kalam from the two tributaries Gabral and Ushu (Fig. 2-3).
Due to the densely populated area, many people live in risk zones (Fig. 2-4c).
Key figures on the 2022 flood in Pakistan
Overall 33 million people have been affected by the floods 2022 in Pakistan. 1,700 people died. More than 800,000 houses were destroyed, 1.3 million houses and 13.000 km of roads damaged.
Response of the Swiss government in Swat Valley
- Rapid response team of 8 experts from Swiss Humanitarian Aid Unit
- SHA implemented project in Swat as contribution to the restoration of basic services

Flood risk analysis in Swat by the SDC/FOEN in collaboration with the PDMA and University of Peshawar.

The Swat river has a relatively steep gradient upstream of Madyan and a generally high bed load transport (left). The bed load is introduced to the main river by many side valleys, and debris flows often occur. Downstream of Madyan, the river has less of a gradient and its width reaches up to several hundred metres (right).

Fig. 2-2 Swat Valley from Madyan upstream (left) and from Khwazakhela bridge. Photos: C. Lehmann

Fig. 2-3 Swat valley, important rivers and hotspot perimeters. Map: P. Walther. SARMAP, OCHA, ESRI Basemap

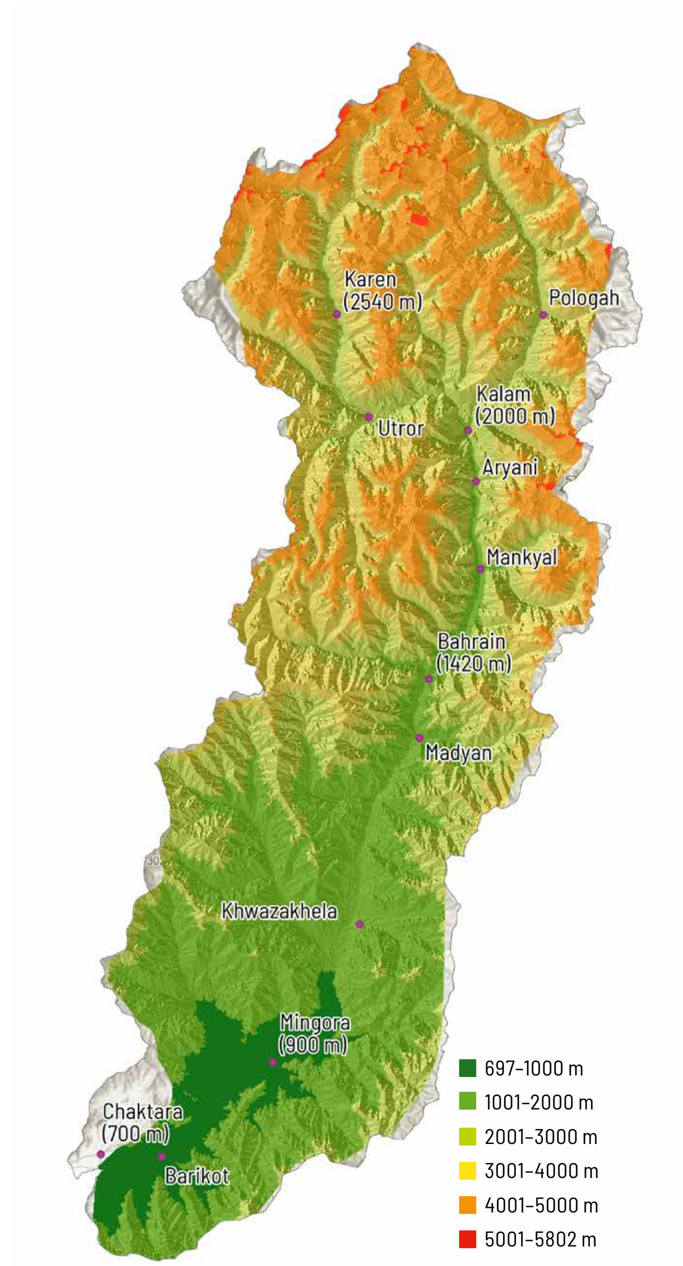


Fig. 2-4a Swat valley and elevation metres above sea level. Map: P. Walther. Copernicus DEM GLO-30, ESRI Basemap

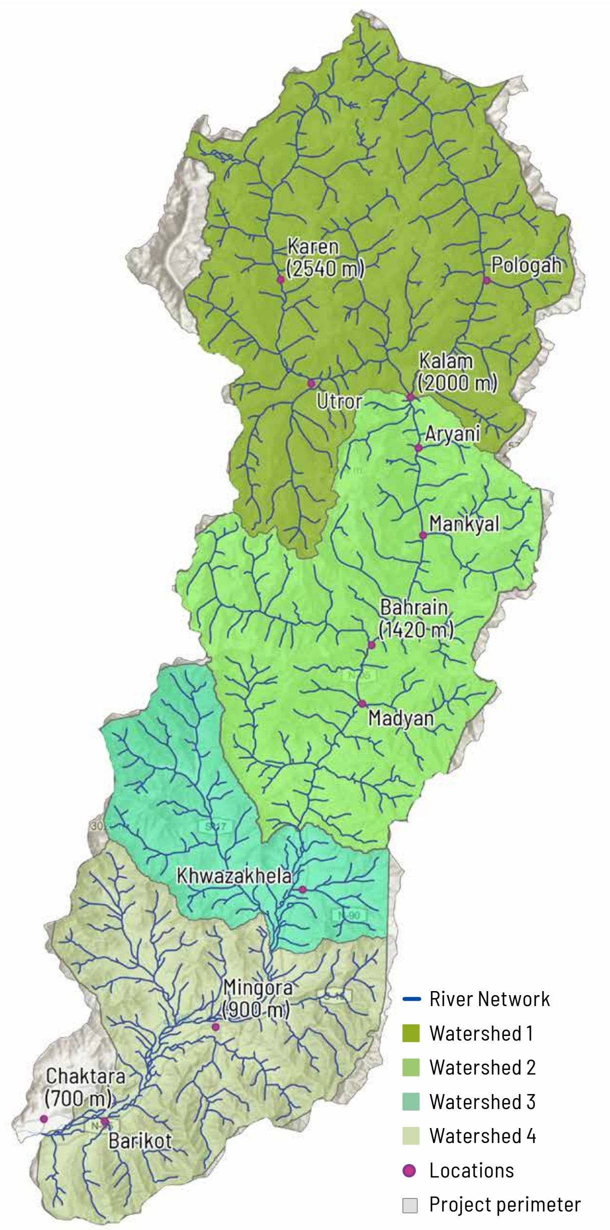


Fig. 2-4b River Network.
Map: P. Walther. SARMAP, ESRI Basemap

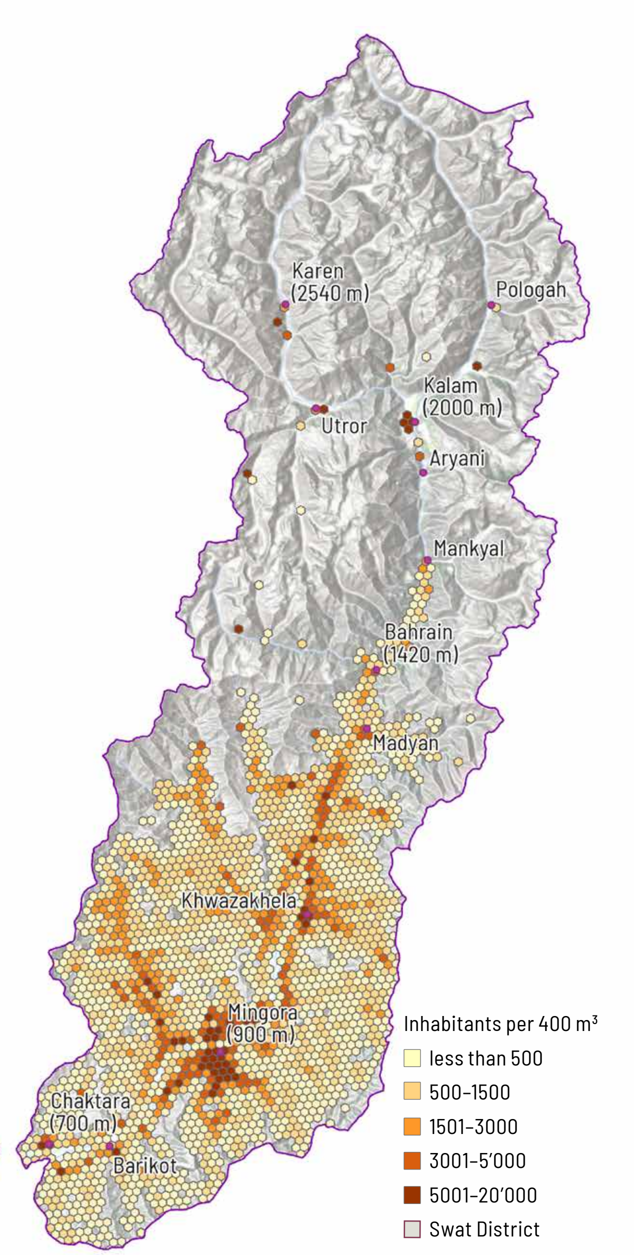


Fig. 2-4c Population density of Swat District is concentrated in southern lowlands. Map: FDFA, SDC, HA-GIS, Kontur population dataset, ESRI Basemap

3. Methodology

The Flood Event Analysis and the present report are based on the concept of integrated risk management (IRM). The NDMA and PDMA also work according to this concept (Fig. 3-1).

Integrated risk management

Risk management is integrated when all natural hazards are considered, all responsible parties (public and private) participate in the planning and implementation of measures, and all types of measures are included in the planning of measures. Integrated risk management requires that a comparable level of safety is aimed for with respect to all natural hazards, which also takes into account all aspects of sustainability: It should be ecologically and socially justifiable and economically proportionate.

Fig. 3-1 Integrated risk management. FOCP, 2009

The study includes on-site field observations supported by spatial data analysis including debris flow calculations and modelling based on satellite and UAV-based aerial survey (drone) images. During a preparatory mission in Pakistan in May 2023, contacts were established with the authorities at all administrative levels, especially with the NDMA and PDMA and the University of Peshawar. The main mission and all fieldwork in Swat Valley took place from 30 May to 18 June 2023, accompanied by two experts from the PDMA, Peshawar.

Site selection for the field assessments

Since it was not possible to visit and assess all sites of damage in the Swat Valley in depth, the following areas were prioritized:

- Areas with major morphological changes or special processes with correspondingly high damage to be investigated and assessed in detail on site, so called "hotspots" (Fig. 3-2)
- Areas with minor changes and correspondingly less damage to be assessed more summarily
- Inaccessible areas to be assessed by remote sensing
- The places visited are (hotspots in bold):
  - Ushu River up to Palogah
  - Gabral River up to Karen and **Utror**
  - **Kalam**
  - Aryani debris flow
  - **Mankyal**
  - **Bahrain** and Daral Valley
  - **Madyan** and Chail Valley
  - Khwazakhela
  - Mingora
  - **Barikot**
  - Chaktara

Fig. 3-2 Towns and locations in the Swat valley.
Map: P. Walther. OCHA, ESRI Basemap

Remote sensing, field mapping and GIS

Before field work, satellite imagery (Sentinel 1 and 2) was used to identify the morphological changes and damage provoked by the 2022 floods, showing the situation before and after the events.

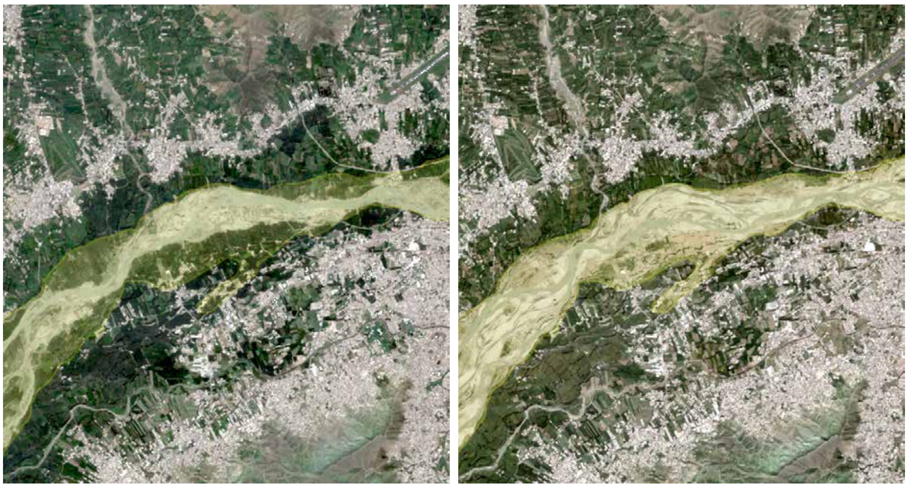


Fig. 3-3 Sentinel-2 colour composite detail pre-event (left) and post-event (right). In both figures the flooded area is highlighted in yellow. SARMAP, Copernicus

To support the SDC study, a team from the University of Peshawar conducted aerial surveys of selected hotspots using drones (UAVs), to acquire and process high-resolution aerial photos and to create digital elevation models (DEMs) and digital surface models (DSMs)

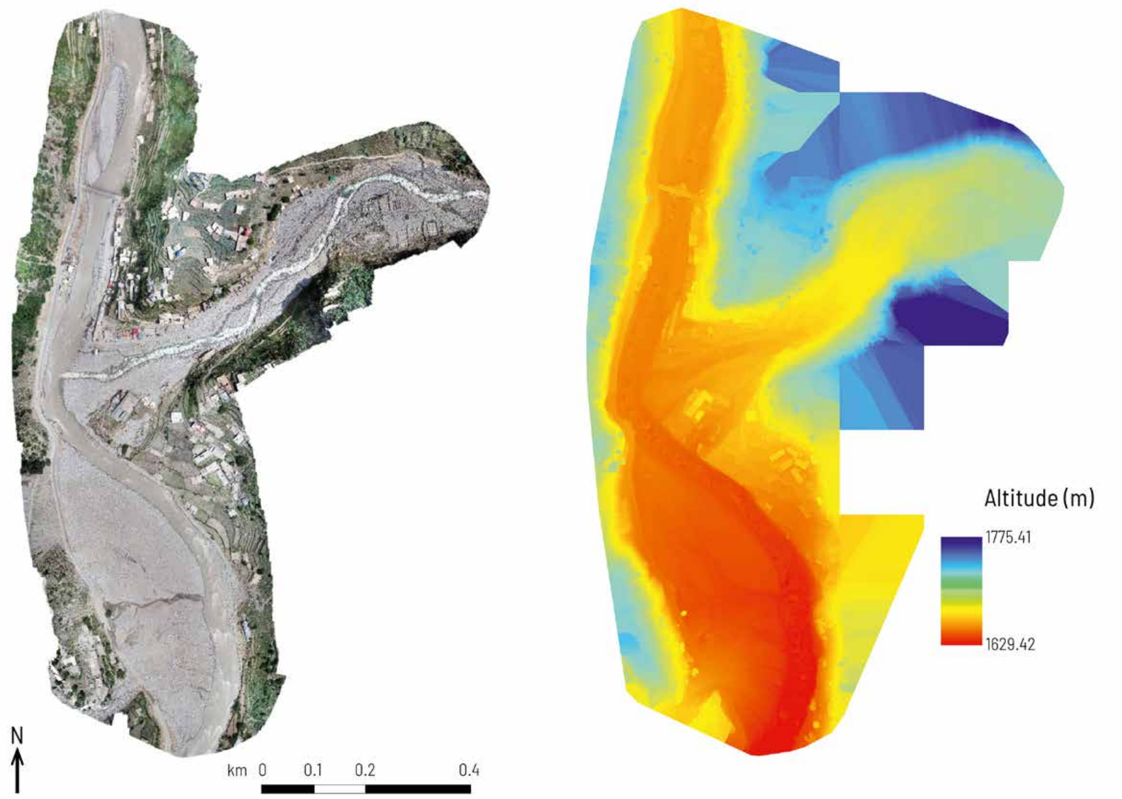
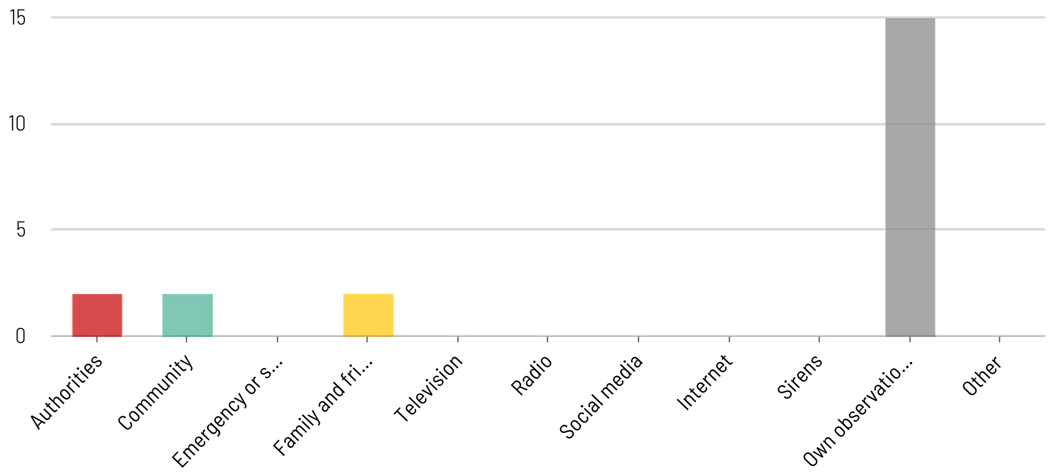


Fig. 3-4 Orthomosaic image (left) and UAV-derived DSM (right) of Mankyal. University of Peshawar

In addition to georeferenced photos and GIS field mapping, the ArcGIS app "QuickCapture" was used to map, document and categorise observations of natural hazard phenomena and damage caused by the flood.

21 standardised interviews with local people were conducted, which were configured with the ArcGIS app "Survey123", to learn about how people experienced the floods and their situation up to now.



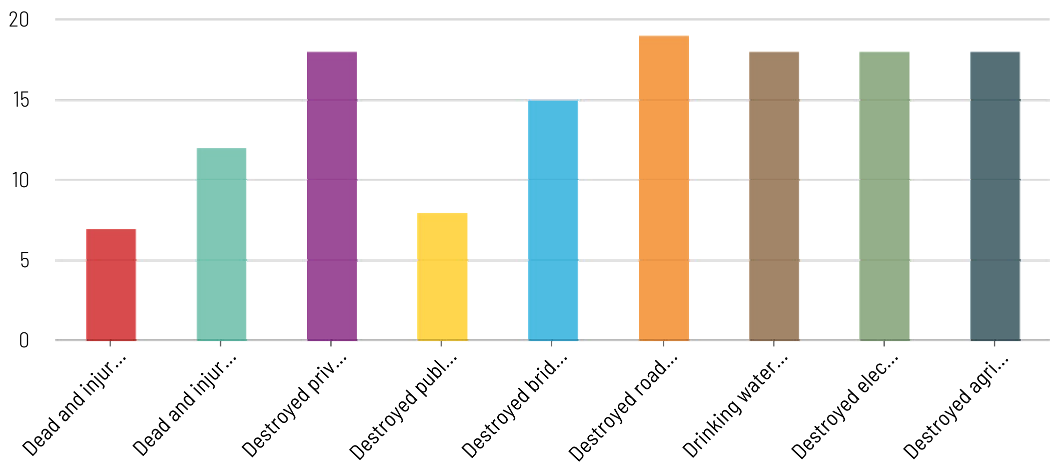


Fig. 3-5 21 Interviews recorded with local community members, about how they were warned (above) and damage (below). SDC Field Team

4. Findings

1. Influence of the massive 2010 floods

The massive floods that occurred in 2010 had a great influence on the floods in 2022. During the last century, one major flood was registered in 1929. Since then, no other flood of this magnitude was recorded in the valley for more than 80 years. Discharge data go back to 1961 and 1983 respectively (Fig. 4-1a, b). Less intense events took place in the 80s and 90s (Fig. 4-1a). People occupied the actual river area, living and farming there. In 2010, the river reclaimed its traditional bed and thus acted practically as a door opener for the 2022 floods. Last year's event took place largely in the wider river area of 2010 (Fig. 4-2).

Fig. 4-1a Annual peak discharge of Khwazakhela station 1983–2022 (data from University of Peshawar)

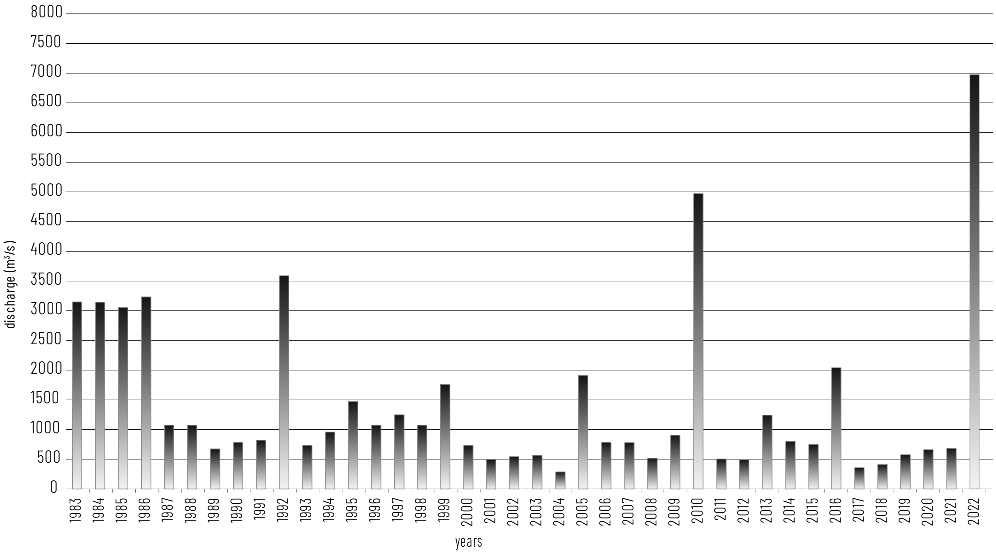
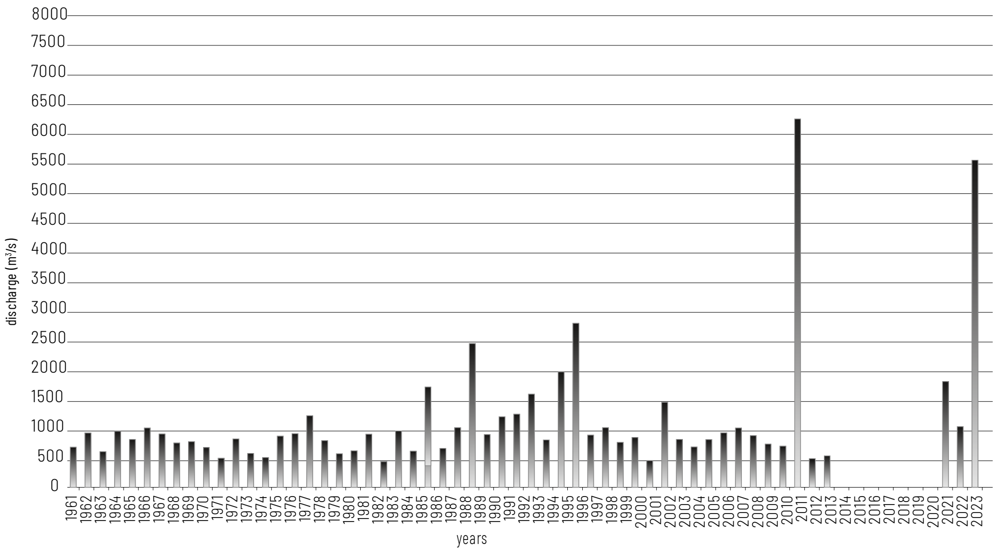


Fig. 4-1b Annual peak discharge of Chactara station 1961–2022 (data from University of Peshawar)



Pre- and post-flood situation in Mankyal after the floods in 2010 and 2022

The pictures show the situation in Mankyal before the flood of 2010 (Fig. 4-2a), and after the flood (4-2b): The bridge from the town to Kalam road has gone (red circle), the river had significantly widened its bed and destroyed also several buildings. Significant damage was caused by the tributary, which destroyed many buildings, mainly because of high sediment transport and accumulation.

During the time until 2022, the bridge over the Swat river was restored and another one constructed. New buildings were constructed at the fan of the tributary, just in the area affected by 2010 (Fig. 4-2c). As a consequence, all these new constructions were destroyed again during the 2022 flood (Fig. 4-2d).

Fig. 4-2a Mankyal 2010. Google Earth

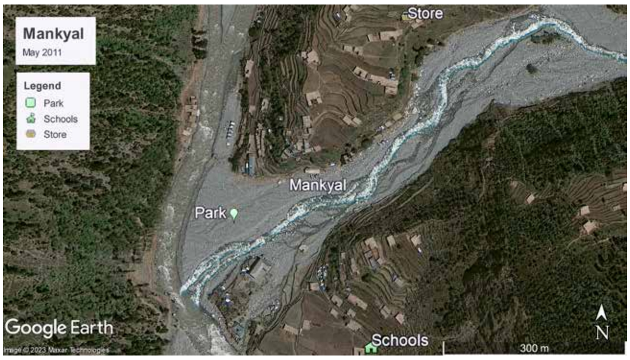


Fig. 4-2b Mankyal 2011. Google Earth

Fig. 4-2c Mankyal 2017. Google Earth

Fig. 4-2d Mankyal 2022. Google Earth

2. 2022 events started off in the north

The event of 2022 started in the far north (Ushu, Gabral). The occurrence of the event was not caused by a single process, but at different locations in the very north of the catchment area. Heavy and persistent rainfall must have been responsible for initiating the event (22–26 August). Unfortunately, this observation has not yet been substantiated by data. However, multiple processes at different locations led to both high water discharge and high sediment transport in the Swat river.

A major sediment impact on the Ushu river resulted from a debris flow destroying parts of Palogah village. At Gabral, around 35 houses were destroyed or flooded.

Fig. 4-3 Debris flow at Palogah village and bank erosion at Gabral village. Photos: P. Walther

3. Debris flows and sediment inputs

Debris flows from the tributaries were responsible for high sediment inputs. Tens of thousands of cubic metres of debris, deposited by debris flows at various locations, overwhelmed the sediment transport capacity of the main river, causing it to accumulate further downstream.

Aryani debris flow is of special importance because of its huge sediment input into the Swat river. The University of Peshawar calculated the volume in the fan of Aryani torrent to be as high as 300,000 m³. It is considered to be one of the important processes in debris input to the Swat river leading to the floods of 2022 downstream in the Swat river.

Fig. 4-4 Aryani debris flow. Photos: C. Lehmann

4. Double damage effects

At different places, debris flows dammed the Swat river and caused double damage effects:

1. Because of the newly built natural dam, the water could not flow downstream, and a lake formed behind the dam and sediments were deposited. This raised both the riverbed and the water level and led to flooding of settlements and fields.
2. After the dam broke, the river eroded material downstream and deposited it at the section indicated in red in the map below. This in turn raised the riverbed. Damage occurred both on the eroded section and where material had been deposited, which resulted in an elevated riverbed and, as a consequence, a higher water level.

Fig. 4-5 Lake formed by Aryani debris flow and sketch of the process of damming and downstream erosion. Photo (left): unknown, map (right): P. Walther. ESRI Basemap

5. Riverbed elevation

Very high sediment transport was observed, which in many places led to significant deposits and riverbed aggradation (e.g. Kalam, Bahrain). The deposits in the riverbed are sometimes over 3 to 4 metres (in Bahrain). The events of 2010 had already led to massive riverbed elevation. In some places such as Kalam and Bahrain, the riverbed is now at the same level as houses and roads.

In Kalam, much of the infrastructure had been built right on the banks and in the forelands of the Gabral river. High sediment transport led to a bed elevation of 2 to 3 metres, with some 150,000 m³ of debris having accumulated there, resulting in great damage to buildings and other infrastructure. There is a high residual risk and damage potential in the future.

Fig. 4-6 Swat river at Kalam, June 2023. Photos: C. Lehmann

In Bahrain, the Swat river was temporarily dammed in 2022 by the Daral river (red), resulting in bed elevation of 3–5 metres. Both rivers transported an immense amount of sediment, so that both riverbeds are now much higher than before. Above all, the bed level of Swat river has reached the elevation of the Bazaar.

All buildings of Bahrain Bazaar along the river were seriously damaged, most ground floors of the buildings became unusable. Already in 2010, there was a significant bed aggradation of several metres.

There is now a high residual risk and damage potential in the future.

Fig. 4-7 Daral river dams Swat river during the 2022 event. Map: FDFA, SDC, HA-GIS, DigitalGlobe

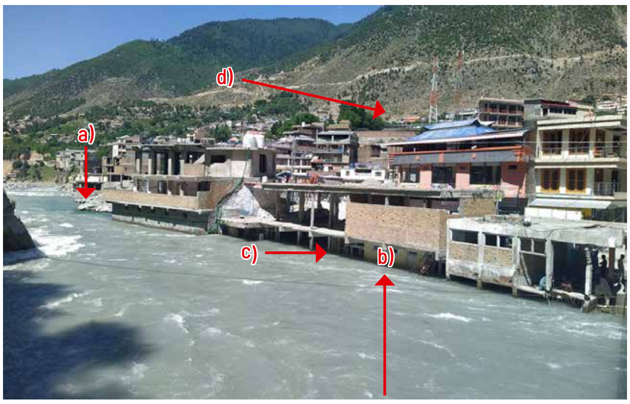


Fig. 4-8 Pictures taken in 2004 (left) and June 2023 (right), showing the difference in bed level.
a) Reference point "rock; b) Riverbed aggradation due to debris and sediments. Increased water level 6–8 m;
c) First floor buildings; d) Forest degradation and deforestation
Photos: Robert Harding Picture Library Ltd (left), P. Walther (right)

Before the flood of 2010, the bed level was very deep and then elevated by debris accumulation during the flood of 2010. To fill out the whole cross-section of the river, it still needed quite a high discharge until 2022. The flood of 2022 again accumulated a huge amount of sediment, resulting in a significant bed elevation (Fig. 4-9, sketch on the right side). From this point on, only a moderate discharge is needed to cause further damage.

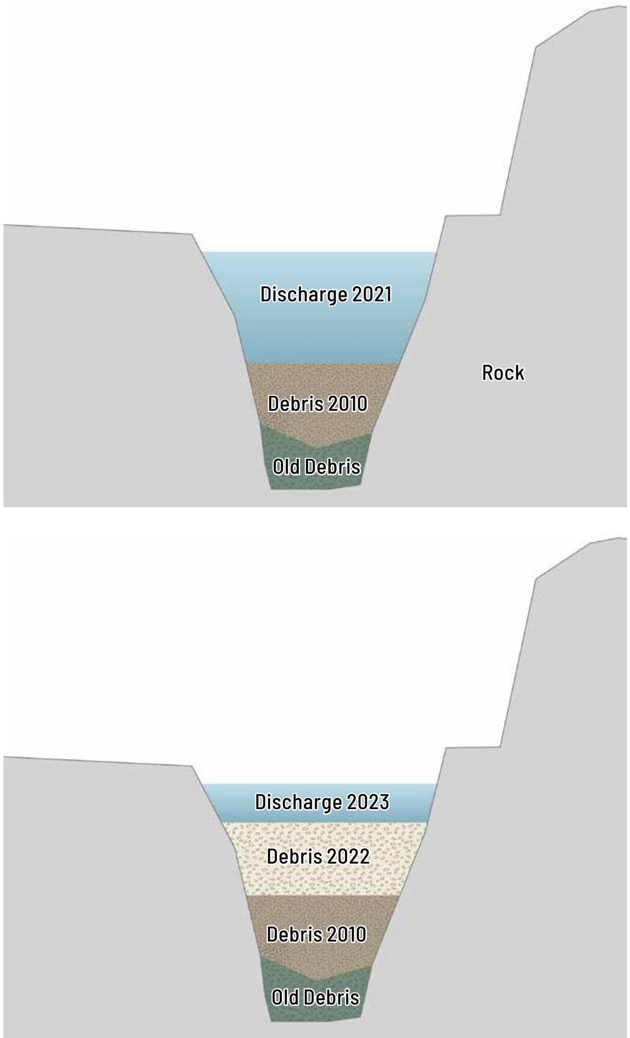


Fig. 4-9 Sketch of bed aggradation in 2010 (above) and 2022. P. Walther

Fig. 4-10 Bahrain before (left) and during event (right). Photos: unknown

6. Riverbank erosion

Bank erosion was massive in many places and led to major damage. Buildings were scoured and undercut or dragged into the river by sliding embankments (Fig. 4-11).

The road to Kalam was destroyed in several places, and many access paths, for example to schools, also disappeared.

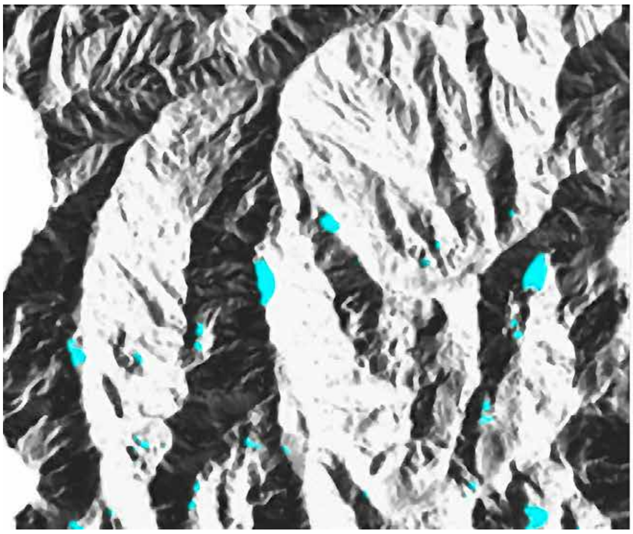
Fig. 4-11 Buildings undercut by bank erosion (left), road washed away and buildings undercut (right). Photos: C. Lehmann (left), P. Walther (right)

7. Landslides

Landslides did not play an important part in introducing sediments to the rivers during the event of 2022. Contrary to previous expectations, no significant landslides were found, and the reason for this could not be determined.

8. Glacial lake outburst floods (GLOF)

Glacial lake outburst floods (GLOFs) were not detected by remote sensing. All mountain lakes in the area still exist as before the flood of 2022 (Fig. 4-12). But the risk of GLOFs in Swat Valley still needs to be taken into account in the future.



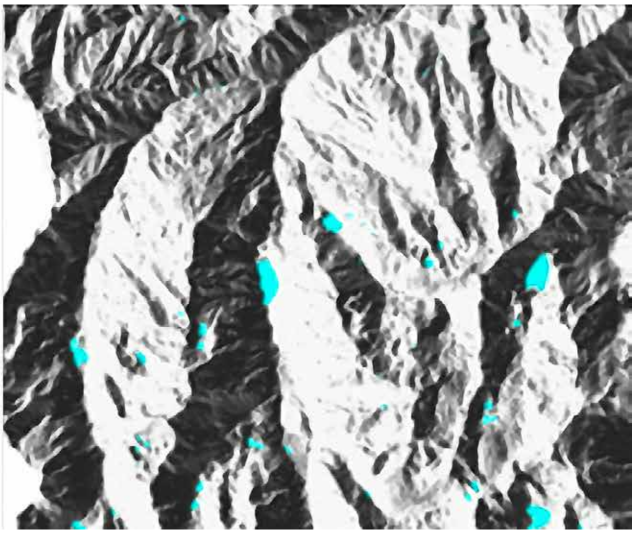


Fig. 4-12 Detail of lakes (blue colour) map of July-early August (left) and September (right). SARMAP, Copernicus DEM GLO-30

9. The human-nature conflict

A high percentage of damage was caused by the human-nature conflict. Prior to 2010, there were already numerous buildings in the riverbed, which were then washed away in the 2010 flood. The buildings were commonly rebuilt in the same place and in the years to 2022, many new buildings were constructed in the area. There has been a law since 2002 which prohibits buildings near the river, but this law is not respected.

Development in Kalam

The development of Kalam from 2009 until after the flood of 2022 is shown in Fig. 4-13. In 2009 the river flows through the village and is relatively narrow. No houses are located directly on the shore. Since then, the town has significantly grown and infrastructure was built near the river. This caused the major damage in 2022 (Fig. 4-13 below).

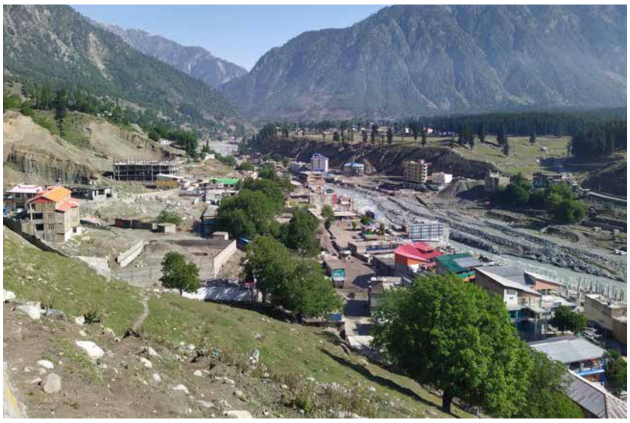


Fig. 4-13 Development of Kalam from 2009 (above) to 2023. Photos: Robert Harding Picture Library Ltd/J. Jackson (above), C. Lehmann (below)

10. Residual risk is very high

The residual risk after the events of 2022 is very high in several places. On the one hand, the riverbed aggradation has meant that much less runoff can now lead to flooding of settlements. On the other hand, the banks have eroded dangerously close to many buildings, so it is only a matter of time until the river undermines these buildings, causing them to collapse.

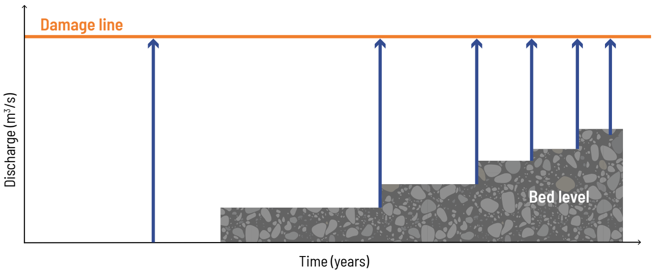


Fig. 4-14 Effect of rising riverbed level on the return period of events. C. Lehmann

Fig. 4-14 explains how bed elevation leads to higher residual risk and more frequent floods. The figure indicates no quantities of discharge or years. The longer the arrow, the more discharge is needed to reach the damage line, the closer they become, the more frequently floods reach the damage line.

With the riverbed at its original level, only a very high discharge might reach the damage line. Such an event occurs correspondingly rarely. As the bed level rises because of debris deposition, the discharge of the next event might be smaller to reach the damage line. With less discharge, the return period of the next events becomes smaller, as indicated in Fig. 4-14 with the arrows becoming smaller and closer and closer together. This has already been observed in Bahrain during spring 2023, as damage occurred already with moderate discharges in the Swat river.

11. Degradation of landscape and forest

Degradation of landscape and forest was observed. Local overuse of the forests and the lack of forest rejuvenation due to heavy grazing with goats is a major factor of degradation. Based on interviews with experts and the local population, as well as on the assessment of historical photographs, it is estimated that the landscape south of Bahrain has recovered locally, and north of it has degraded. The influence of climate change on the forest cannot be assessed due to lack of data.

However, there is a lack of consolidated forest management plans and the legal basis for sustainable forest management. The lack of forest regeneration due to over-aged stands and high grazing pressure has resulted in an unbalanced age class structure and species mix in the forest stands. Possible future changes in the local climate with higher temperatures and changes in annual precipitation may destabilise the forests in the future and move the vegetation limits upwards. As a result, forest vitality and stability are at risk. Calamities with forest pests, storms, fires, etc. may increase.

Fig. 4-15 Degradation of forest and landscape. Photo: P. Walther

12. Previous land stabilization projects have shown beneficial effects

Previous projects of the Forest Department of Pakistan and the SDC have been effective and the small stabilising constructions in small gullies survived the event of 2022. Local reforestation measures were also successful and have a positive effect on surface erosion processes.

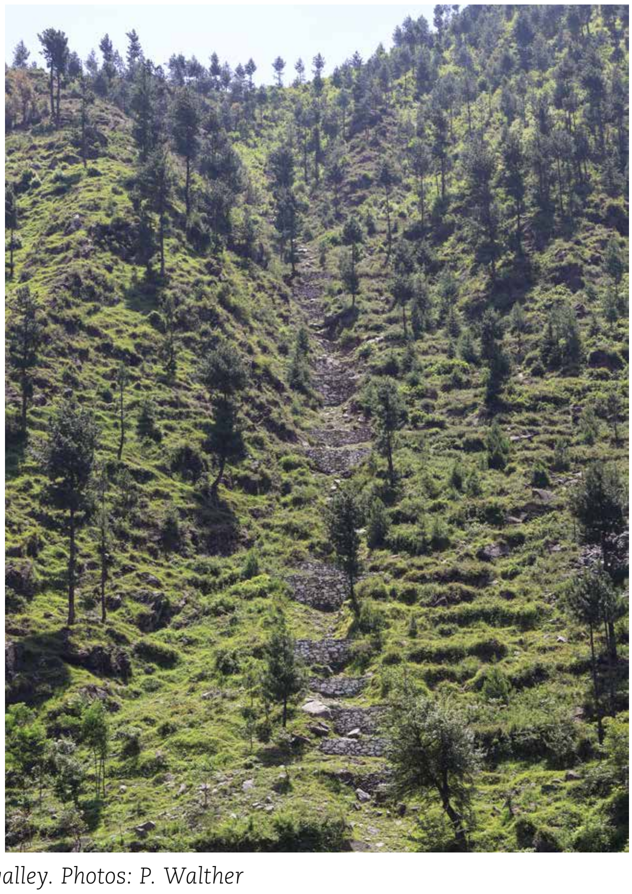


Fig. 4-16 Small stabilising constructions in Chail valley. Photos: P. Walther

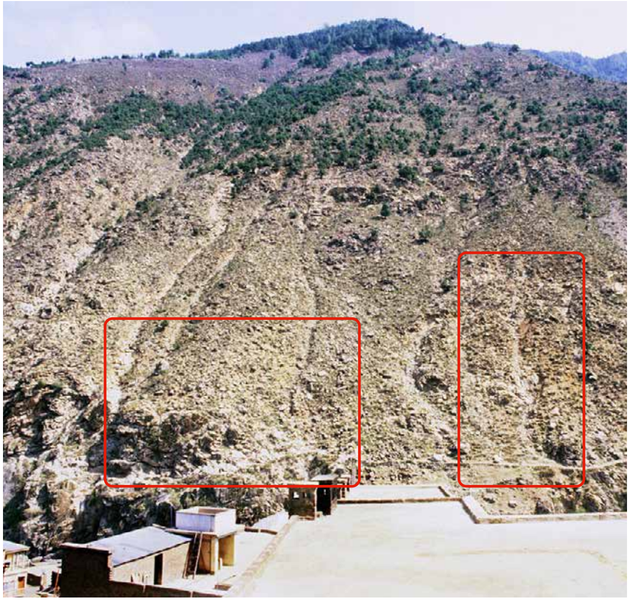


Fig. 4-17 Counter slope photograph Bahrain 1985, before grazing ban and afforestation had positive effects.
Photo: F. Berger

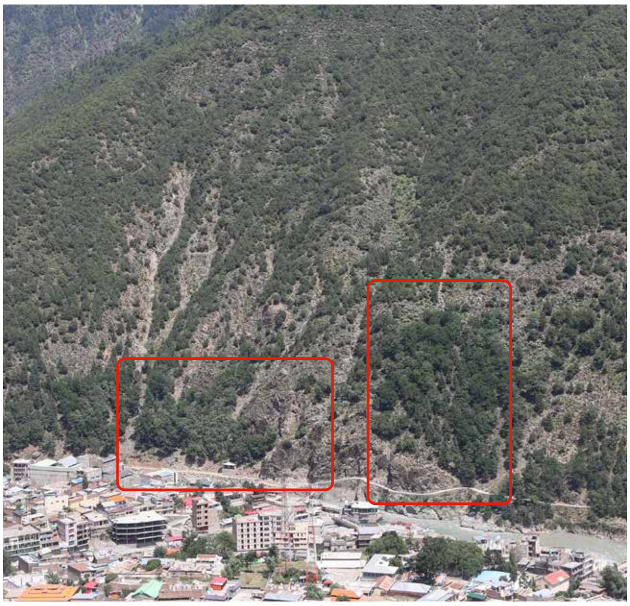


Fig. 4-18 Reforestation, coordinated and financed by the Swiss development cooperation (Bahrain 1992).
Photo: C. Lehmann, 2023

Some results of the 21 interviews with the local population

Question	Answer (affirmative)	Nr.	Answer (negative)	Nr.
Did you receive a flood warning?	yes	3	no	18
Were you able to escape to safety?	yes	19	no	2
Are there evacuation plans in your family or community in case of flood?	yes	14	no	7
What time of day were you hit by the flood?	Daytime	18	Night	3
What was the main problem, water or debris?	Water and debris or debris only	19	Water only	2
Was the house built before 2010 ?	yes	17	no	4
Will the houses be rebuilt on the same site?	yes	12	no	9
Is it possible to rebuild the object in another place?	yes	16	no	5
What help and support did you receive?	The public service sent in a task force	3	We could help ourselves in the community/ We did not receive any help in the first days	18

Due to the small number of interviews, they are not representative of the population of the Swat Valley. But as the interviews with local people indicated, the problem was the lack of warnings, especially in the remote areas. A warning system is needed. The majority were able to escape from the flood and find a secure place to be for a while, and some said they had had an evacuation plan. The fact that the event occurred mainly during the day may have reduced the loss of life. Most of the inhabitants helped themselves and will rebuild in the same place as before, but a minority will find another location if possible.

5. Conclusions and recommendations

The 2010 flood influenced the 2022 flood. Without the 2010 flood, the 2022 flood would have been different in terms of its evolution, morphological behaviour and the damage it caused. But both events were too big to be brought under control by humans. Such major events cannot be mitigated or prevented by technical measures. The amount of water and debris is too large for this. The damage in 2022 was not caused by a single triggering event, but by a number of processes that complemented and interacted with each other to produce the damage. Furthermore, the event of 2022 showed clearly the spatial conflict between humans and nature, and it looks like this effect will intensify in the future. In recent years, the population of Swat has increased sharply and the pressure to settle in high-risk areas is rising. That means that also more damage must be feared for the future. As a result of river bed aggradation, also minor discharges and thus a higher frequency of flooding are to be feared. This means damage is likely to occur more frequently and, in some cases, more intensively. As an important effect of this, potential risk of damage has increased in many places in comparison to before 2022. As things stand, the event showed no direct evidence of climate change. The available data do not indicate significant changes in the discharge regime of the Swat river to Chaktara. The mere fact that two major events take place in a short space of time after a long period of time does not contradict the statistical findings. In addition, the data are insufficient to make a direct comparison between the two major events of 2010 and 2022. More profound data evaluation is required to answer that question. However, potential trigger conditions such as the possible influence of permafrost processes or the formation of debris flows in the retreat area of glaciers could not be investigated and needs more attention in the future.

The risk of future damage is very high, especially on river stretches with extreme deposits and bank erosion. In Bahrain, several floods have so far resulted this year (2023) from not unusual rainfall and from increased runoff due to snow melt only. The only connecting road from Bahrain to the tourist resort of Kalam has already been interrupted several times. If persistent and intense monsoon rains occur, the damage will be very high.

For the sake of sustainability considerations, cost benefit ratio, and as a result of the feasibility of quality, capacity and efficiency of constructional measures, structural DRR measures will not be recommended. Locally, such measures could perhaps offer some protection, depending on the intensity of the event. However, such structural measures usually shift the problem downstream.

In order to present and make known the processes and risks highlighted here in future projects, the following is recommended:

1. **Capacity building and exchange of knowledge at different levels.** Capacity building is important at different levels and on different topics. Above all, all activities should be coordinated with the PDMA and possibly with the University of Peshawar, as well as within local communities.

2. **Multiple hazard risk mapping** to allow a precise definition of who and what is at high, medium or low risk from various natural hazards. However, the capacity to create these maps needs to be built up (universities, authorities). It serves as a basis for land use planning later on and has also to look into questions of climate change and the risks of GLOFs.

3. **Continuation of restoration of critical community infrastructure** (pedestrian bridges, school paths for children, hydropower etc.). Although many roads and bridges were rebuilt shortly after the event, there are many provisionally created constructions which urgently need a sustainable solution (build back better). And there are still large gaps for safe access routes and pedestrian crossings. It should therefore be requested to build flood-proof roads, paths and important infrastructure.

4. **Ensuring sustainable water supply**. A joint system involving several communities exploiting a single water source could contribute to a more sustainable use of water resources and should ensure water availability even in the case of a natural hazard.

5. **Enforcement and compliance with existing laws.** In 2002, the North-West Frontier Province Rivers Protection Ordinance 2001 was enacted, prohibiting construction closer than 200 feet to the river. The law is apparently not well known and is not enforced everywhere.

6. **Coordination in river management.** For river construction work, there should always be an overall river basin concept. An agency responsible for this should be able to carry out coordination tasks, so that all protection works carried out on the river are part of the concept and do not negatively impact downstream areas.

7. **Define standards for engineering works.** Many constructions were destroyed due to a lack of expertise in river morphology and engineering. The extent to which standards actually exist and in reality are applied is uncertain, but safety could be improved by enforcing certain minimum standards.

For a detailed evaluation, data was missing. Unfortunately data for the event analysis was not available, either because the measuring stations were not in operation or because they are non-existent. To fill this gap, the following suggestion is made:

8. **Establish a meteorological data network for Swat.** A reliable measurement network forms the basis for analyses as well as for predictions and warnings and hazard mapping.

9. **Set up an early warning system (at two or three hydrometric stations)** to protect lives. For this, several conditions must be met, including reliable data, and reliable threshold values for alarming etc.. This will require time to be established (see also point 8). There are many questions and uncertainties to be resolved in order to establish a functioning and reliable early warning system, but as the interviews showed, a need for warning is there.

Degradation of landscape and forest was obvious at some locations. Loss of land, destabilisation of slopes and higher sediment input into gullies and rivers might result. To prevent this, the study recommends:

10. **Sustainable forest management and afforestation**, which can reduce the impact of certain natural hazard processes in mountain areas and have potential for a local wood-based value chain. Local afforestation optimises the water storage capacities of the soil and helps to reduce soil erosion during heavy rains. Small structures reduce gully formation, provided they are built professionally and as part of an overall concept.

11. To support sustainable forest management, among other things a **long-term photography and GIS monitoring and analysis concept is suggested.** Pakistani and foreign organisations started photographic monitoring of landscape development in Swat Valley in the 1980s. Using this knowledge and data, a future photo monitoring set-up should be established and supplemented with additional stand locations.

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Imprint

Editor:
Federal Department of Foreign Affairs
Swiss Agency for Development and Cooperation SDC
Swiss Humanitarian Aid Unit
3003 Bern

Layout:
Audiovisual Service, FDFA Communication

Cover photograph:
Sakadi Baba after the floods in 2022, © SDC Field Team

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