Madi River, Nepal

Landslide dam outburst flood risk management

Narendra Raj Khanal, Tribhuvan University; **Achyuta Koirala**, Fulbright Consultant; **Sher Bahadur Gurung**, Tribhuvan University; **Umesh Kumar**, Geometics Solutions Pvt. Ltd; **Rishi Rijal**, Consultant; **Salikram Sigdel**, Tribhuvan University; **Chitra Acharya**, Consultant; and **Upendra Prasad Yadav**, Geometics Solutions Pvt. Ltd

The Madi River is at risk of landslide dam outburst flood, with potential property loss estimated at between USD 25 million and 68 million. With 14 hydropower projects proposed in the area and numerous settlements downstream, mitigation in terms of landslide control is needed urgently.

Introduction

Landslide dam outburst floods (LDOFs) are common in Nepal's high, steep, and fragile mountains with their deep and narrow gorges (Shrestha 2008). More than 12 major LDOFs resulting in loss of life and property were reported in Nepal between 1967 and 1996. Despite this, Nepal has no specific policy or programme for managing LDOF risk. Although very different in nature (and in the strategies required to manage them), LDOFs are considered together with other water-induced disasters in national policies.

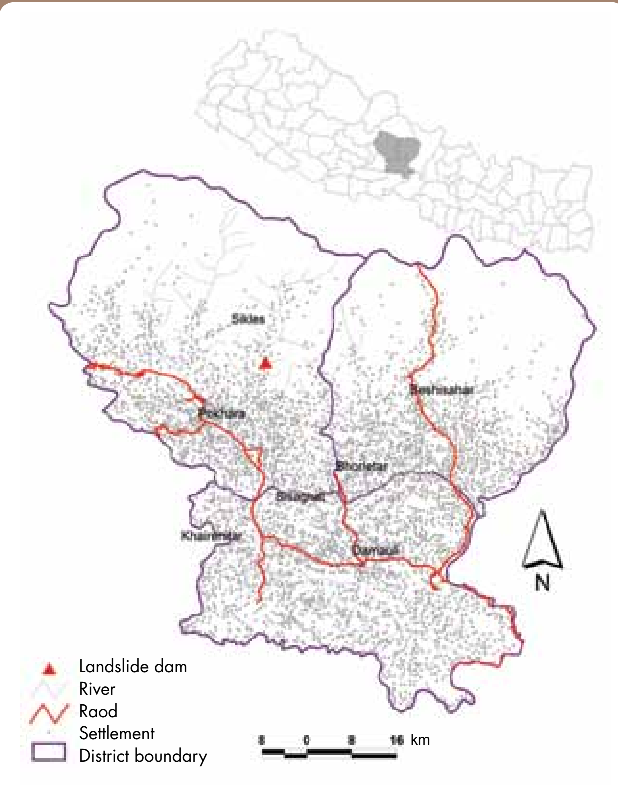
On 3 August 2010, the Madi River in western Nepal was dammed by a landslide at Naune village in Sildjure VDC, Kaski District putting people in Kaski, Lamjung, and Tanahun districts at high risk (Figure 20).

Photographs taken during a reconnaissance survey of the landslide dam and inundated area in February 2011 show numerous cracks along the crown of the landslide and a large volume of hill slope materials that are likely to fail in the future and dam the Madi River again. Accordingly, a study of the risk of landslide dam outburst flood (LDOF) was proposed to:

- estimate the volume of materials damming the river, the potential volume of materials that may slide down in the future, the volume of water stored behind the dam, the potential volume of water that may be stored in the future, and the area at risk of inundation;
- assess slope stability and estimate the probability of failure, including process and causes, in and around the Nanung landslide;
- identify other potential landslide damming sites along the Madi River;
- assess community vulnerability;
- estimate sector-wise and reach-wise the monetary value of likely damage from a LDOF along the Madi River; and
- make recommendations for LDOF risk management.

The outcomes of the study were a comprehensive report on vulnerability to landslide dam outburst flood with recommendations for risk management, a landslide hazard map, and a detailed topographic map.

Figure 20: **Location of Madi River landslide dam**



Methodology

The study was carried out in three phases: deskwork, fieldwork, and data analysis. As part of the deskwork, aerial photographs, satellite images, analogue maps, and photographs of the study area were collected and interpreted. A landslide inventory map was prepared to identify potential areas of landslide initiation and damming. A total of 10 parameter maps – slope gradient, slope aspect, land use and land cover, elevation zone, geology, lineament, distance to river, distance to road, slope shape, and precipitation – were prepared. A bivariate statistical approach using remote sensing and GIS for data input generation was used to produce a landslide hazard map along the Madi River. Checklists were prepared for the collection of socioeconomic data to quantify elements at risk of LDOF on the Madi River; these were administered during focus group discussions and key informant interviews.

Fieldwork consisted of three components: the verification of potential landslide hazard maps and potential sites for landslide damming; the geotechnical investigation of hill slopes and landslides including a total station survey; and the collection of socioeconomic data. Field mapping and the measurement of the morphometric characteristics of the landslide, landslide dam, and channel geometry were carried out around the 3 August 2010 dam site. Soil samples were collected and analysed in the laboratory to assess the soil properties of the slip plane. The causes of landslide were determined by analysing precipitation data, the morphometric profile of the landslide, the hill slope materials of the landslide and its surrounding areas, and local people's perceptions.

After determining the height of the dam likely to be formed (based on the results of the total station survey) and volume of materials likely to be moved from the landslide (through geological and geotechnical survey), three landslide dam outburst flood scenarios were fixed: up to 5 m, 5–10 m, and 10–15 m. These three flood zone scenarios were delineated in topographical maps and information was collected to assess the risk in each zone.

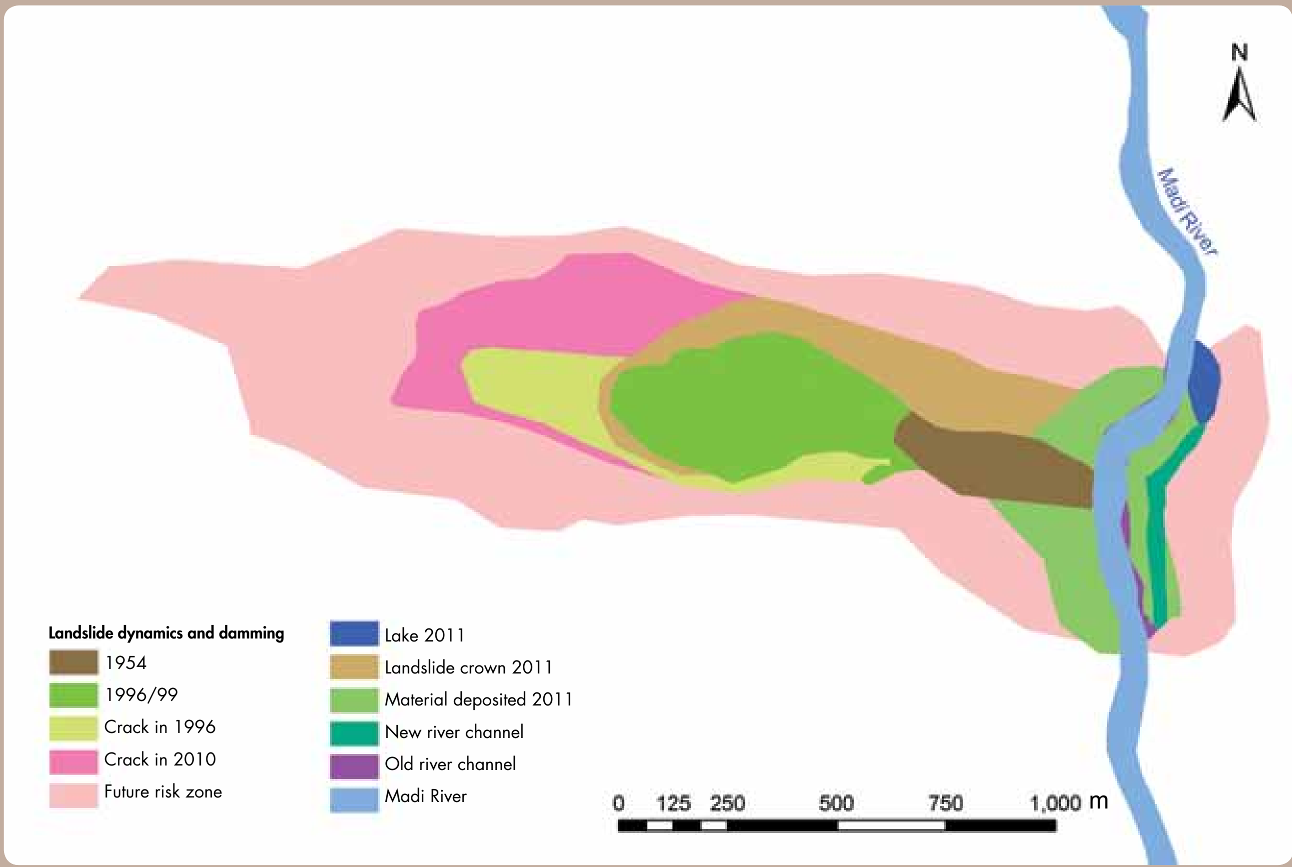
Information on the frequency of landslides, landslide dams, floods, and debris flows; their causes; past loss/damage from such events; socioeconomic vulnerability; and past risk reduction activities were collected through focus group discussions, key informant interviews, transect walks, direct observation, and social mapping. During focus group discussions, locals were asked to map the area likely to be affected by landslide dam outburst flood based on past experience and quantify the elements (tangible and intangible) exposed in these flood prone areas. Finally, they were asked to map and describe risk reduction activities carried out in the past and were recommended activities to reduce the risk of LDOF, in particular, and flood and landslide and debris flow, in general. The monetary value of exposed elements likely to be affected by LDOF was quantified using local prevailing purchase values for household assets (land, crops, and livestock) and replacement cost for infrastructure. A per unit cost at the national average was used to estimate the replacement cost of larger infrastructure such as roads and hydroelectricity facilities. All values were expressed in current prices.

The river reach from the damming site to the confluence of the Madi and Seti rivers near Damauli was divided into 16 blocks for the collection of relevant socioeconomic information. At least one focus group discussion with 7 to 13 community members was organized in each block. An integrated sustainable livelihood approach was adopted to assess the socioeconomic vulnerability of communities likely to be affected. Vulnerability as a result of low adaptive capacity was determined by access to physical, natural, social, and financial capital and assets. Information was collected on access to such capital and assets, and on demographic characteristics, size of landholdings, employment and income diversification, level of food sufficiency, social networks, and access to health services, water supply, and markets.

Results

The Nanung, which is also known as Naune or Taprang, landslide was initiated in 1933 and reactivated and extended in 1946, 1952, 1985, and 1996 (Figure 21). It started to move again on 3 August 2010, completely blocking the river for about five hours. The lake that formed behind the dam was 40 m deep and extended about 0.8 km upstream. When the water overtopped, it flowed through the landslide mass blocking the old river channel, inundating irrigated paddy fields about 50 m east of the riverbank. Eighteen days later, on 21 August 2010, the river cut the dam and formed a new channel a few metres east of the old channel with a flood wave about 4 m high. On 23 August 2010,

Figure 21: **Dynamics and damming of the Nanung landslide**



the river cut the dam and the left bank of the river generating a 5 m flood downstream, which damaged a suspension bridge at Chasu, among other things.

Precipitation data recorded at Sikles about 6 km north of Taprang and the discharge recorded 39 km downsteam at Sisaghat were analysed revealing that the landslide reactivated because of high volume precipitation in July and the improper management of surface and irrigation water. The impact of the landslide dam and outburst flood can be seen as far as 39 km downstream from the damming site.

Based on the assessment of landslide susceptibility, the study identified potential sites of damming (Figure 22), although it is difficult to estimate the duration and magnitude of future flooding. Three processes of river damming were identified by the study: damming by flooded tributaries joining at a right angle with sharp bend; damming by logs and debris brought by the river along the narrow river channel section; and damming by material moved from the landslide and debris flow. To date, only landslides and landslide dam outburst floods have resulted in a threat to the downstream study area.

Figure 22: **Potential sites for damming**

The Nanung landslide is 1,744 m long from the bank of the Madi River to the active crown on the top of the landslide and 1,110 m wide at its end on the Madi riverbank. Its minimum width is 672 m slightly below the middle part of the landslide. The landslide is mainly composed of sand and silt with gravel and a little clay.

The maximum possible volume of landslide debris from the Nanung landslide (worst-case scenario) was estimated to be about 18.82 million cubic metres. It was assumed that 50 per cent of the total volume of debris derived from the landslide would reach the accumulation zone and spread homogeneously. The rest of the material is likely to be adjusted in maintaining the future slope morphology of the landslide. However, a nominal volume of the finest components of soil particles is likely to be washed away by the Madi River. Hence, the total volume of the material to reach the accumulation area is estimated to be 9.41 million cubic metres. The area of the accumulation zone on the bank of the Madi River is estimated to be 395,549 m^2. The height of the dam formed by the landslide in the Madi River (worst-case scenario) would be 23.8 m. Based on this estimated dam height, and the width and slope of the riverbed, the peak discharge in the event of landslide dam outburst flood is estimated to be about 726 m^3 per second. This would result in a catastrophic flood extending far downstream.

An estimated 2,584 households, with a corresponding population of around 14,059, would be affected by a 15 m high LDOF in the Madi River (Table 8; Figure 23). The market centres of Gumle, Satrasaya, Rambazar, Mugrebesi, Birdi, Duipiple, and Damauli (Shantinagar) are at the risk together with 19 hotels and one industrial unit (in the event of a 5 m high LDOF); 47 hotels and three industrial units (10 m high LDOF); and 93 hotels and 10 industrial units (15 m high LDOF). Sabi, Bhaise, Ghumlebazar, Rambazar, and Satrasay areas are more susceptible to LDOF in terms of likely damage to hotels and industrial units. A total of 14 hydroelectricity projects with a total capacity of 386.9 megawatts have been proposed in different reaches of the Madi River. These projects are also likely to be affected if proper mitigation and adaptation measures are not taken.

The estimated total value of all the elements exposed to LDOF of the Nanung landslide on the Madi River is between USD 24 million (5 m high LDOF) and USD 68 million (15 m high LDOF) (Table 9).

Table 8: **Elements exposed to potential LDOF on the Madi River**

Elements exposed	Flood level		
	5 m	10 m	15 m
Households (number)	963	1,736	2,584
Population (number)	5,276	9,491	14,059
Irrigated land (ha)	265	473	678
Unirrigated land (ha)	6	34	80
Crops (tonnes)	1,749	3,512	5,328
Livestock (number)	1,496	6,681	15,270
Concrete houses (number)	4	44	179
Non-concrete houses (number)	50	214	400
Sheds (number)	53	145	277
Housing plots (ha)	0.6	2.5	6.4
Roads (km)	1.8	5.4	14.4
Trails (km)	5.3	8.9	13.5
Transmission lines (km)	1.6	3.8	8.4
Motorable bridges (number)	2	3	5
Suspension bridges (number)	3	8	11
Temples (number)	14	24	42
School buildings (number)	1	4	8
Office buildings (number)	4	13	30

Although, local people are aware of the risks posed by landslides, debris flows, and floods, control and management activities have not received priority in an organized way. When a landslide first occurs, it is usually seen as the problem of the individual landowners directly affected. After a few years, the landslide and gullies become enlarged and the problem starts to affect more people, requiring huge amounts of resources and technology to control. Government efforts to manage the risk of landslide, LDOF, and flood are mainly focused on rescue and relief operations. The distribution of food, clothing, tents, medicine, and, in some cases, cash is the main activity so far implemented in the area. At the community level, the main activities include afforestation and the construction of retaining walls and spurs. However, these activities are scattered and not properly planned keeping in mind the need to improve the watershed condition. Measures adopted at the household level to control landslides and debris flows include diversion of surface runoff near the crown, the draining of water from the main body of the landslide, construction of retaining walls, plantation, and protection from livestock grazing. These activities are generally practised on private land.

Janajatis (indigenous ethnic groups) and Dalits (so-called 'untouchable' Hindu caste groups such as

Figure 23: **Number of households exposed to LDOF of different flood levels**

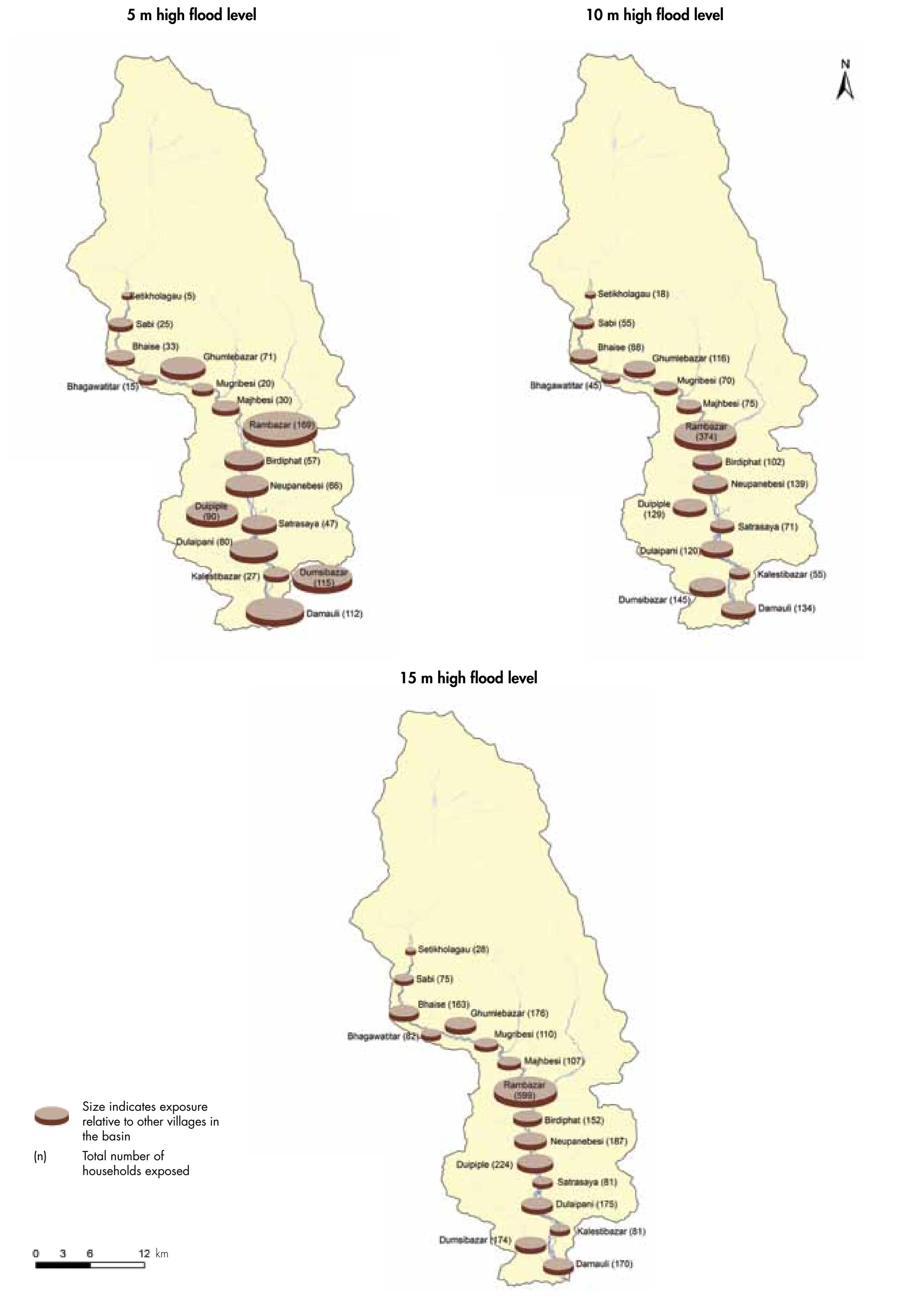


Table 9: **Estimated monetary value exposed to LDOF on the Madi River**

Type of property	Value (USD 1,000)		
	Up to 5 m	<10 m	<15 m
Real estate	18,804.5	35,423.6	55,793.6
Agriculture	853.7	2,023.4	3,444.5
Infrastructure	3,929.3	5,239.9	8,676.1
Total	23,587.5	42,686.9	67,914.2

Damai, Kami, Sunar, and Sarki) comprise about 49 per cent of the families exposed to LDOF hazard in the area. These groups are generally marginalized with limited access to resources and decision making. The literacy rate among exposed households is low and dependency ratio high. Landholding size is also low. Nearly 5 per cent of families are landless, 15 per cent are marginal, and 40 per cent are small farmers. Only 45 per cent of families produce enough food from their own land. Hence, the investment capacity of local people to mitigate and manage potential LDOF risk is minimal, although the area is highly accessible from roads and connected with major market towns and cities.

Key Findings

- The impact of the landslide dam outburst flood on the Madi River on 3 August 2010 can be seen as far as 39 km downstream from the damming site.
- If the Madi River is dammed again, the dam could be up to 24 m high with a potential peak discharge of 726 m^3 per second, which would have catestrophic effects far downstream.
- An estimated 2,584 households would be affected by a 15 m high LDOF in the Madi River, with a corresponding population of around 14,059.
- The economic value of elements exposed to LDOF on the Madi River is between USD 24 million and USD 68 million.
- Although local people are aware of LDOF risk, their capcity to mitigate and manage the risk is weak.
- The government has not prioritized risk management, focusing efforts on rescue and relief rather than preparedness or mitigation.

Recommendations

- Identify potential sites of damming using remote sensing and GIS technology and inform local people about the risk of potential LDOF.
- Monitor landslides along rivers such as the Madi River, including the type, volume, and movement of materials, to estimate the extent and duration of future damming and the magnitude of any outburst flood.
- Take action to control landslides along the riverbank at the initial stage of failure to save resources and reduce risk.
- Conduct proper land use planning; manage surface and irrigation water through the construction of catch drains and flexible spurs; and undertake bioengineering measures to stabilize landslides and guide debris flows.
- Develop and implement land use guidelines and building codes to reduce the risk posed by floods, including LDOFs.
- Develop an institutional mechanism at the watershed level to control landslides, improve watershed condition, and establish an early warning system, together with cost-benefit sharing mechanisms between local communities, those downstream, and hydropower development projects.
- Prioritize preparedness planning for landslide and flood risk management and coordinate and properly plan efforts to manage risk keeping in mind the need to improve the watershed condition.
- Make local people, particularly in high-risk zones, aware of the risk of LDOF and provide them with skills development training for preparedness planning and rescue and relief operations.