

Chapter 18

Landslides Inventory and Trans-boundary Risk Management in Koshi River Basin, Himalaya

Jianqiang Zhang, Amar Deep Regmi, Rongkun Liu,
Narendra Raj Khanal, Luca Schenato, Deo Raj Gurung
and Shahriar Wahid

Abstract Koshi River basin, which is a trans-boundary basin shared by China, Nepal and India, covers an area of about 87,500 km². This study investigated the landslide locations in this basin by means of interpreting remote sensing images as well as field work. We could map 5653 landslides that are located within China and Nepal. Landslide caused different kinds of disasters including damage to public and private properties. The most common hazard pattern is supplying sources to debris flow, accounting for 48.38% of the number of landslides. The following patterns are soil erosion and blocking river, accounting for 25.18 and 18.98%, respectively. Cascading hazards related to landslides are very common in Koshi River basin. Three main cascading events were found there: landslide-dammed lake-outburst flood, GLOF-landslide and landslide-debris flow. These features make the disasters extend temporally and spatially. A framework for risk management in trans-boundary river basin was proposed to develop cooperation at academic and administrative levels among the involved countries.

J. Zhang (✉) · A.D. Regmi

Key Laboratory of Mountain Hazards and Earth Surface Processes, Institute of Mountain Hazards and Environment, Chinese Academy of Sciences, Chengdu, China
e-mail: zhangjq@imde.ac.cn

R. Liu

School of Environment and Natural Resources, The Ohio State University,
Columbus, OH, USA

N.R. Khanal

Central Department of Geography, Tribhuvan University,
Kirtipur, Kathmandu, Nepal

L. Schenato

National Research Council of Italy, Research Institute for Geo-Hydrological
Protection (CNR-IRPI), Padua, Italy

D.R. Gurung · S. Wahid

International Centre for Integrated Mountain Development (ICIMOD),
Kathmandu, Nepal

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A. Li et al. (eds.), *Land Cover Change and Its Eco-environmental Responses
in Nepal*, Springer Geography, DOI 10.1007/978-981-10-2890-8_18

Keywords Landslide inventory · Trans-boundary · Koshi River basin · Himalaya

18.1 Introduction

Due to the Himalayan region's rugged topography, active tectonics, soft and fragile rocks, frequent earthquakes and concentrated rainfalls during monsoon periods, landslides have become the most devastating hazards with characteristics of wide distribution, large quantity and high frequency (Laban 1979; Dhital et al. 1993; Dahal and Hasegawa 2008). Every year landslides cause casualties and huge economic loss, and they even prove to constrain economic development in certain regions of the basin.

Landslide risk management is an essential method for risk reduction and mitigation. The basic work for the management is landslide inventory, which includes causative factors collection, characteristics analysis and landslide investigation. The following step is calculating the potential loss caused by landslide. The final work is mitigating or avoiding the risk by means of engineer control, landslide avoidance and disaster response. Generally, landslide risk management includes four phases: the first and basic phase is landslide inventory, which is based on remote sensing, geographical information system technology and field work; the second phase is landslides susceptibility and their hazards assessment, aiming to show the area being prone to sliding and to know their scale and frequency; the third phase is to identify the elements that would be effected by landslides so as to carry out risk assessment; the last phase is to manage the landslide data, to establish methods of engineering and ecological control as well as to make evacuation route and carry out escape training.

Like in other mountainous regions, several researches have carried out landslide investigation (Shorder and Bishop 1998; Hewitt 1998; Khattak et al. 2010), susceptibility assessment and risk evaluation in the Himalayan region (Dahal et al. 2008; Kamp et al. 2008; Das et al. 2010). However, in this region there are many trans-boundary rivers, i.e., their up reaches and down reaches belong to different countries. Sometimes the risk induced by landslide crosses border line and affects several other counties downstream. This fact brings new issues for landslide risk management. The Koshi River basin, a trans-boundary river basin located in the central Himalayas, was taken as the study area. Landslide investigation was conducted based on both remote sensing image interpretation and field work. Disaster patterns and cascading events related to landslide are summarized. A framework for trans-boundary landslide risk management is finally discussed.

18.2 Study Area

Koshi River is located in the central Himalayas and is a major tributary of the Ganges River. It is a trans-boundary river that covers parts of China, Nepal and India. The upper reaches of the Koshi River basin consists of mountainous region

belonging to Nepal and China, where landslides predominate, whereas the river flows through flat land in India; hence, flooding occurs frequently there.

The upper reach of the Koshi River contains three tributaries: the north tributary is the main stream named as Arun River, the west one as Sun Koshi and the east one as Tamor. After the three tributaries join together, the river is named as Koshi River (Fig. 18.1).

The topography of the Koshi River basin ascends from south to north. Elevation rises from 60 m (outlet of Koshi River) to 8844 m (Mountain Everest) and descends to near 4000 m at the north side of Mountain Everest, which is the southern edge of Tibetan Plateau. The physical features of the basin can be classified into 9 divisions from north to south: Terai, Siwalik Hills, Mahabharat Lekh, Middle Mountains, Transition belt, Great Himalaya, Inner Himalaya, Tibetan Marginal Range and Tibetan Plateau (Ives and Messerli 1989).

The climate in the Koshi River basin ranges from tropical to frigid significantly correlated with elevation from south to north. The basin receives most of the



Fig. 18.1 Location of Koshi River basin

precipitation from July to October (monsoon season), and the precipitation varied regionally and temporally there. Tropical climate zone locates in the south of the basin with elevation lower than 1000 m. Subtropical zone locates in the region with elevation of 1000–2000 m. The region with elevation of 2000–3000 m is temperate climate zone. The subtemperate climate zone locates in the region with elevation of 3000–4000 m. The alpine climate zone locates 1000 m up to the subtemperate climate zone, and the snow line is above 5000 m generally.

18.3 Dataset and Methodology

Landslides include a wide range of mass movements controlled by gravity. Various scientific disciplines have been developed to define the types of landslides. Landslide classification is mainly based on the type of material and type of movement. The material types include rock, earth, soil, mud and debris, and the movement types include fall, topple, slide, spread and flow. Landslide classifications are the combination of the two terms, such as rock fall, rock slide, earth slide, earth spread. (Varnes 1978). In this study, debris flow is not included because its mechanism is different from other landslide types.

Topographic maps, Landsat ETM/TM and Google Earth were utilized to identify landslide boundaries. Topographic maps were created based on the aerial photographs taken in 1992. Landslides were marked on the maps (Fig. 18.2a), and then digitalized landslide boundaries were produced. In this way, a total of 3559 landslides were obtained in Koshi basin in Nepal. Alternatively, Landsat ETM/TM image were used to identify landslides by manual image interpretation (Fig. 18.2b). Google Earth supplies high-resolution remote sensing imageries (Fig. 18.2c), where small landslides can be recognized. Because of the low precision of these data

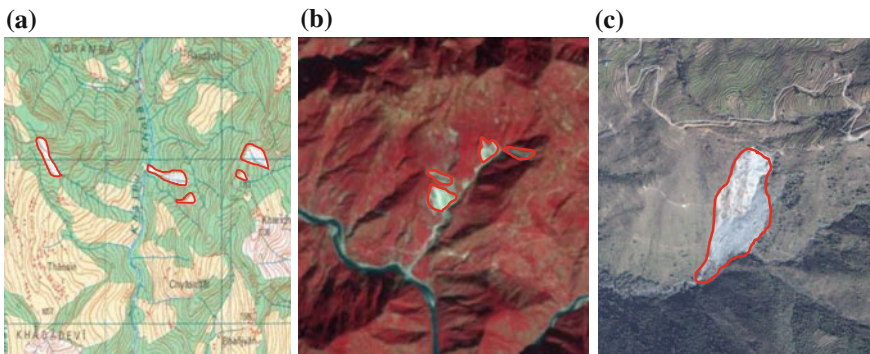


Fig. 18.2 Landslide identified by topographic map and remote sensing images: **a** landslides in topographic map, **b** landslides in Landsat ETM image, **c** landslides in high-resolution image from Google Earth

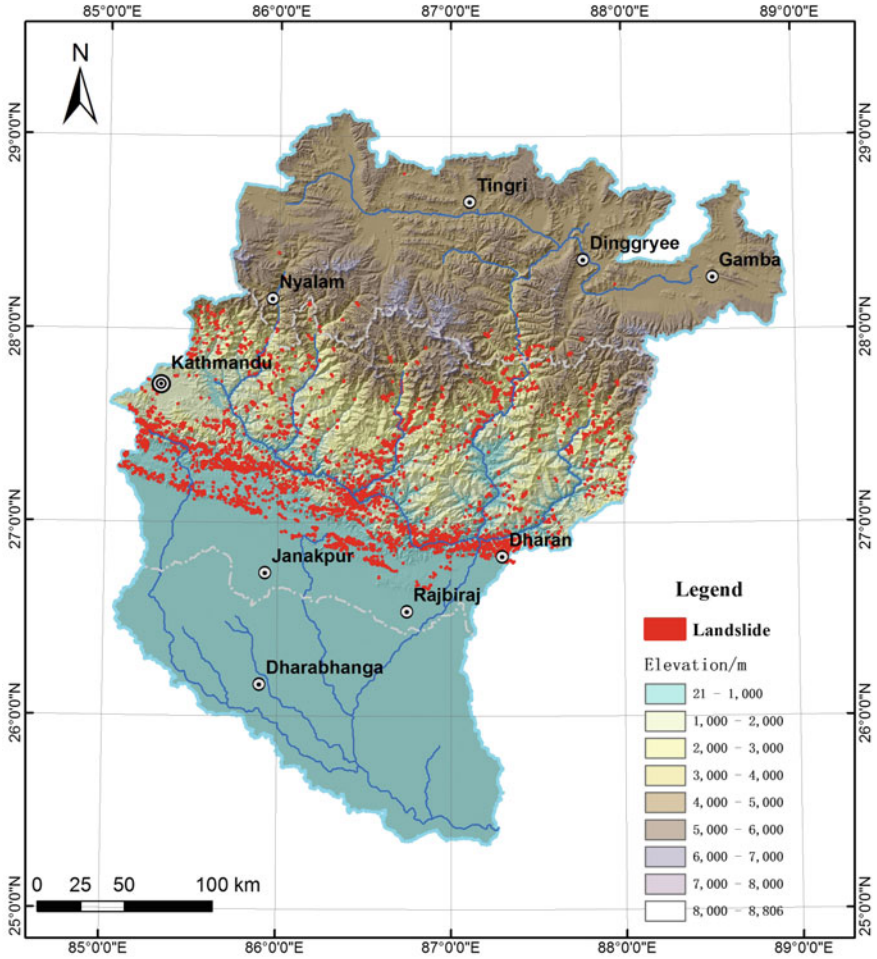


Fig. 18.3 Landslides distribution map in the Koshi River basin

source, Landsat ETM imageries and ASTER DEM data were therefore used to adjust the location of landslides. Thus, a total of 3402 landslides were mapped in the Koshi River basin, of which 3285 landslides are located in Nepal and the remaining 117 in China (Zhang et al. 2016).

By combining these two sets of landslide data and deleting overlapped landslides, we finally mapped a total of 5653 landslides in the Koshi River basin (Fig. 18.3).

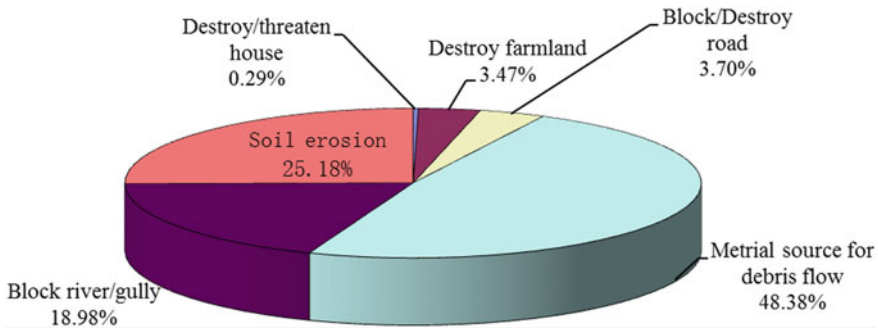


Fig. 18.4 Landslide hazard patterns in the Koshi River basin

18.4 Disasters Induced by Landslides

Landslides cause many damages in the Koshi River basin. The disasters induced by landslides are summarized into six types: threaten or destroy buildings, destroy farmland, destroy and block road, block river, supply sources to debris flow and erode soil.

Based on remote sensing image interpretation as well as other related publications and reports, we counted the number of landslide as per different hazardous patterns (Fig. 18.4). If a landslide triggers more than one type of hazard, it will be counted multiple. Statistic result shows that most landslides supply sources to debris flows and this situation takes up 48.38% of the number of landslides. The second most common hazard pattern is the soil erosion, which accounts for 25.18%. The third is the river blockage, which accounts for 18.98%.

18.4.1 Threaten or Destroy Buildings

The houses located on landslides or along the landslide runout areas will suffer tremendous destruction (Table 18.1). By destroying houses, landslides always bring in casualties and economic loss. The hazard patterns depend on the relative location of buildings to landslides. Cracks are formed at the back of landslide, while sliding occurs at both sides of a landslide. Houses in these parts will first show some cracks, which expand as the landslide moves. Buildings located on the landslide body will incline at the beginning and then be destroyed when the landslide body crushes. The houses in front of landslides will always be buried by landslide body.

Few landslides destroyed or are threatening buildings in the Koshi River basin. But once the threatening landslide destroys the building, it always brings casualties and property loss. The Jure landslide destroyed 24 houses, and Zhangmu landslide is threatening 453 buildings in total.

Table 18.1 Examples of landslides that destructed or are threatening houses in the Koshi River basin

Landslide	Location	Damage	Time
Rumeila landslide	Zhangmu Town, Nyalam County, China	14 buildings destroyed	2000
Zhangmu landslide	Zhangmu Town, Nyalam County, China	453 buildings threatened	2014
Suspa landslide	Suspa VDC, Nepal	23 houses threatened, 14 houses cracked	1986
Gairimudi landslide	Gairimudi VDC, Nepal	1 building destroyed, 14 buildings cracked, and 23 buildings threatened	September 15, 2010
Manamaiju landslide	Manamaiju VDC, Kathmandu, Nepal	1 building destroyed	2013
Jure landslide	Jure village, Ramche VDC, Nepal	24 buildings destroyed	August 2, 2014

- Zhangmu Landslide

Zhangmu, a town located in Nyalam County, Tibet Autonomous Region, is a first-level land port of China to Nepal. Zhangmu landslide is located on the left bank of Boqu River at the south foot of the Himalayas. The whole town is located on an ancient high-positioned landslide body (Fig. 18.5). This ancient landslide deposit is the main stratum in this area, with 0–7 m depth loose slope deposition on the top. The area of Zhangmu landslide is 1.48 km², with an average depth of 66.17 m and a volume of approximately 9793.16×10^4 m³. Free faces were formed in the south, north and west directions due to the erosion of Zhangmu gully, Bangcun east gully and Boqu River. The biggest cutting depth of Boqu River, Zhangmu gully and Dianchang gully is 180, 40 and 70 m, respectively (Li and Wen 1995). This region is influenced by the Indian monsoon and has a humid subtropical monsoon climate. Annual precipitation is 2400–3100 mm, and the highest daily precipitation can reach up to 93.2 mm. The precipitation is mainly concentrated in the months from June to September, which accounts for 80% of the whole-year precipitation (Mao 2008). In the past, the landslide stayed stable under natural or saturated condition. However, in the last decade several infrastructures have been constructed in Zhangmu, and they increased the load of landslide body. In the meantime, more precipitation in this region has been observed than before. These turned to be the main triggering factors that reactivated Zhangmu landslide. Some new and shallow landslides were formed in the front and sides of the ancient landslide, imposing direct threat on the premises of Zhangmu.

There are 4 communities in Zhangmu with 1774 residents. A total of 453 buildings are identified in Zhangmu town on Google Earth image dated on January 16, 2014. At present, cracks appeared in some houses and on the national road in the front of Fuliuyan landslide. The cracks are still enlarging and expanding. The depression has become severe in front of the police station.

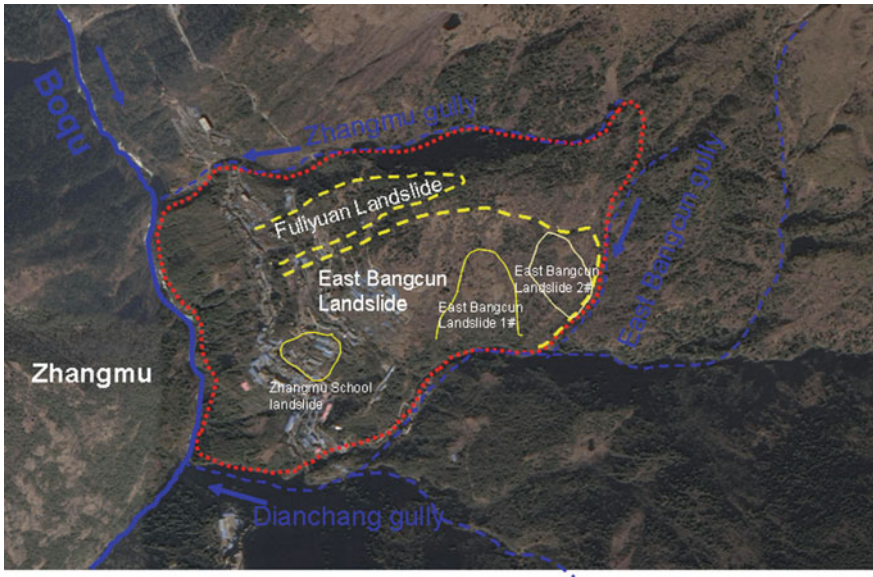


Fig. 18.5 Overview of Zhangmu landslide: the whole town is located on the landslide

18.4.2 Destruction of Farmland

Since arable lands are very limited in mountainous region due to constraints of terrain, most of the farmland is reclaimed on the slope or river terrace. The reclamation has changed land cover types and influenced runoff production and infiltration. In addition, irrigation increased the moisture of soil. As a result, the farmland located on landslides is at risk of collapse and gliding, while that at the foot of hill is always prone to being buried.

Take the landslide that centered at $27^{\circ} 37' 10.39''\text{N}$, $86^{\circ} 06' 33.46''\text{E}$ near Kahriswara village, Gairimudi VDC, Nepal for example, the absolute elevation of the slope is 1256 m and the relative elevation to the gully is nearly 124 m (Fig. 18.6). This landslide has become active since 20 years ago. On October 15, 2014, the landslide collapsed because of continued rainfall for weeks. Nearly $350,000 \text{ m}^3$ of debris slid down along the slope and destroyed the farmland on the landslide body. The landslide then moved to the hill foot and buried parts of farmland. In total, 3 ha of farmland was destroyed by this landslide (Sudmeier-Rieux et al. 2012).

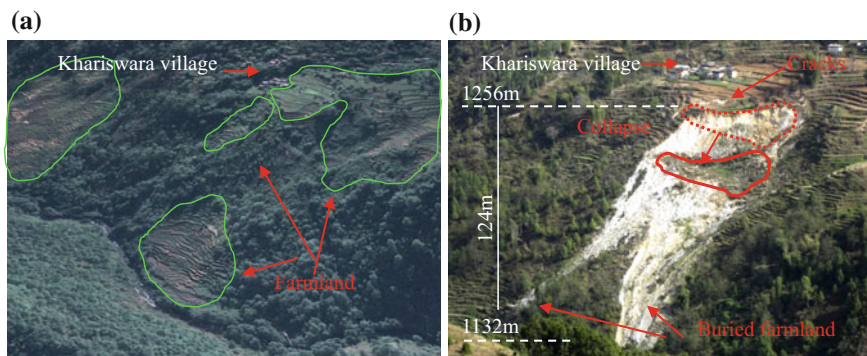


Fig. 18.6 Landslide occurred in the Khariswara village, Nepal and destroyed farmland: **a** before landslide (Google Earth), **b** after landslide (Sudmeier-Rieux et al. 2012)

18.4.3 Destruction and Blockage of Road

Road construction in general is a large, complicated and belt-shaped project. On one hand, as roads always encompass different geomorphologic and geologic units, they are oftentimes at risk of different kinds of geo-hazards. On the other hand, evacuation and waste slog by road construction disturbs geologic environment along the road and destroys the stability of hill slopes. Therefore, landslides usually developed along roads. Although landslides occurred only at one or some points along the road, they could block or destroy sections of the road and affect the whole transportation connected by the road.

Many important highways are located in the Koshi River basin, including National Road G318 in China, Arniko Highway, Lamosangu–Jiri Highway, Nayapool–Ramechhap Highway, B.P. Highway and East–West Highway in Nepal (Fig. 18.7). The road G318 joins the Arniko Highway to form the Sino–Nepal friendship road. Along the highway from Dhulikhel, Nepal to Zhangmu, China distributes 106 landslides, among which 26 landslides affect the highway directly. The Sun Koshi landslide, which occurred on August 2, 2014, destroyed the Arniko Highway for 2 km. As a result, the Arniko Highway, a major trade link between China and Nepal with trade exchange standing at nearly NPR 38 million per day (nearly USD 400,000) was blocked for nearly two months. Specially permitted by the Chinese government, a lot of goods were transported to Gyirong Port, Nepal, via an alternative trade route which though did not officially open at that time. Such natural disaster would mean serious medium-term impacts for Nepal. The landslide mass also damaged two gates of Sun Koshi hydropower plant, and the powerhouse of Sanima Hydropower project was submerged. Power supply from several other hydropower plants in the valley, including Bhote Koshi, Chaku and Larcha, was interrupted due to collapse of transmission lines. The interruption led to the country's scheduled power cuts (Shrestha et al. 2014).

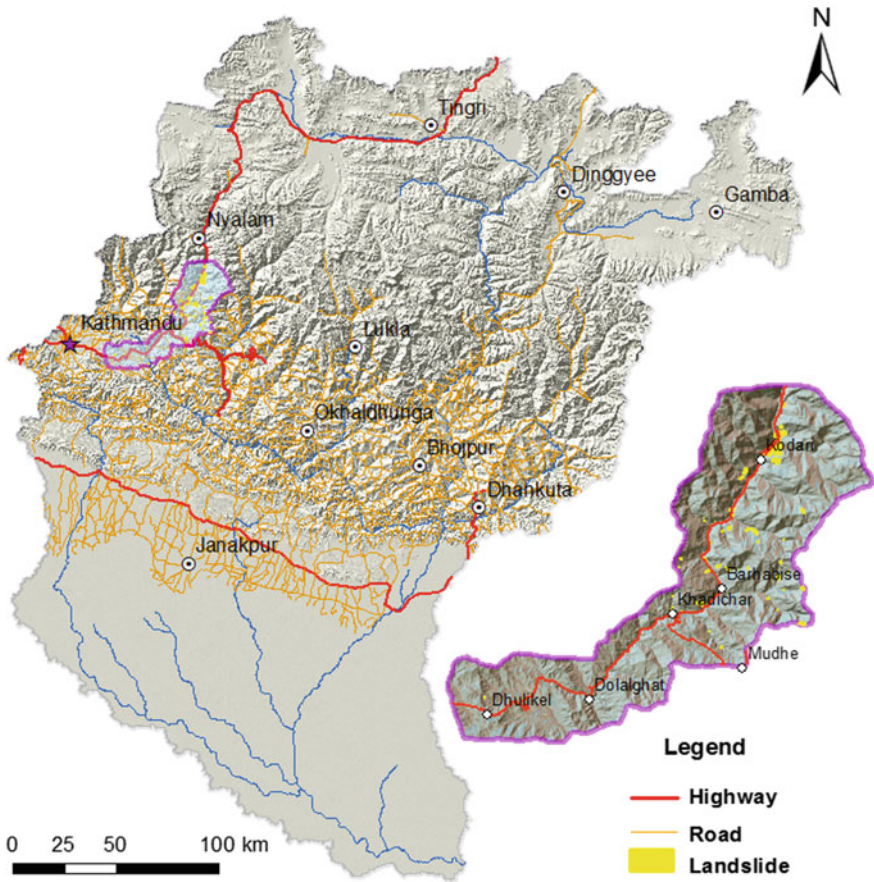


Fig. 18.7 Road networks and landslides along Arniko Highway

18.4.4 Supply Sources to Debris Flows

Debris flows are widely distributed in the Koshi River basin. Landslides play a significant role in supplying abundant materials to debris flows (Fig. 18.8). Generally speaking, landslides are the source of debris flows in two patterns. In one pattern, landslide is directly transformed into debris flows, while in other pattern landslides move to hill foot and block gully to supply sources to debris flows.

18.4.5 Block River

In alpine regions with deep-cutting gorges, river bank is prone to landslides because river erodes both banks to form free faces. Landslides are widely distributed along

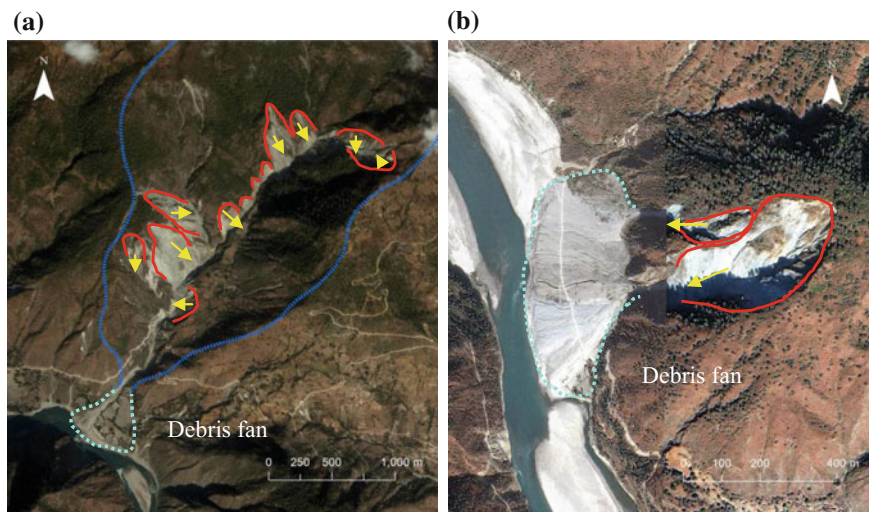


Fig. 18.8 Patterns of landslides supplying sources to debris flows: **a** landslides block gully and supply material sources, **b** landslides transform into debris flows

the river and move easily from banks into the river. Large landslides can change the channel of river or even block the river and form dammed lake. Jure landslide that occurred on August 2, 2014 blocked Sun Koshi River, a branch of Koshi River, for more than 45 days.

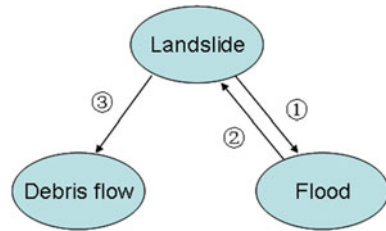
18.4.6 Soil Erosion

Landslide is one kind of severe gravitational erosion. In this study, the analyzed landslides did not directly trigger any of aforementioned hazards. The mass of landslides just deposits on slope.

18.5 Cascading Hazards Related to Landslides

Sometimes landslides do not happen alone. Other kinds of hazards, such as floods or debris flows, may be triggered before or after landslides. This can be called a hazard chain or cascading hazards. In the Koshi River basin, there are three kinds of cascading hazards related with landslides in general: landslide-dammed lake-outburst flood, GLOF-landslide and landslide-debris flow (Fig. 18.9).

Fig. 18.9 Cascading hazards related to landslides



18.5.1 Landslide-Dammed Lake-Outburst Flood

When a large-scale landslide occurs on the riverbank, sometimes it blocks the river and forms a dammed lake in the upstream. The dammed lake can inundate villages, roads and farms along the river. With an increasing water level, the water will surge over the dam or the dam will collapse under water stress and then comes the outburst flood. The burst flood can destroy villages, roads, farmlands or even threaten the cities downstream.

- Jure landslide and dammed lake

Jure landslide is located on the right bank of the Sun Koshi River, 1.4 km upstream of Sun Koshi hydropower station. It is a deep landslide with an average depth of more than 25 m. The width is approximate 500 m and the length is 1500 m. The relative altitude from slope foot to the back scarp is 1440 m (Fig. 18.10). The landslide buried Jure village. Dozens of houses were destroyed or buried, and more than 156 people were killed (Pokharel et al. 2014). The landslide blocked the Sun Koshi River and formed a dammed lake. The height of the dam was about 70 m, and the length of the dammed lake along the river was 1250 m. The dammed lake, although no longer exists at present, inundated the Arniko Highway as well as some farmlands upstream (Shrestha et al. 2014).

18.5.2 Landslide-Debris Flow

Landslides and debris flows usually occur simultaneously. Landslides supply loose mass to debris flows; debris flows erode the bank of gully, affect the stability of slope and trigger more landslides. In particular, areas that have been hit by earthquakes are prone to collapse and landslides. In a certain period after earthquake, debris flows will prevail as the main type of mountain hazards. This is typical during Kashmir earthquake in 2005 and Wenchuan earthquake in 2008. In these two cases, large amount of landslides were triggered and then debris flows became extremely active. This is also the case in the Koshi River basin, where landslide-debris flow is the most common hazard chain.

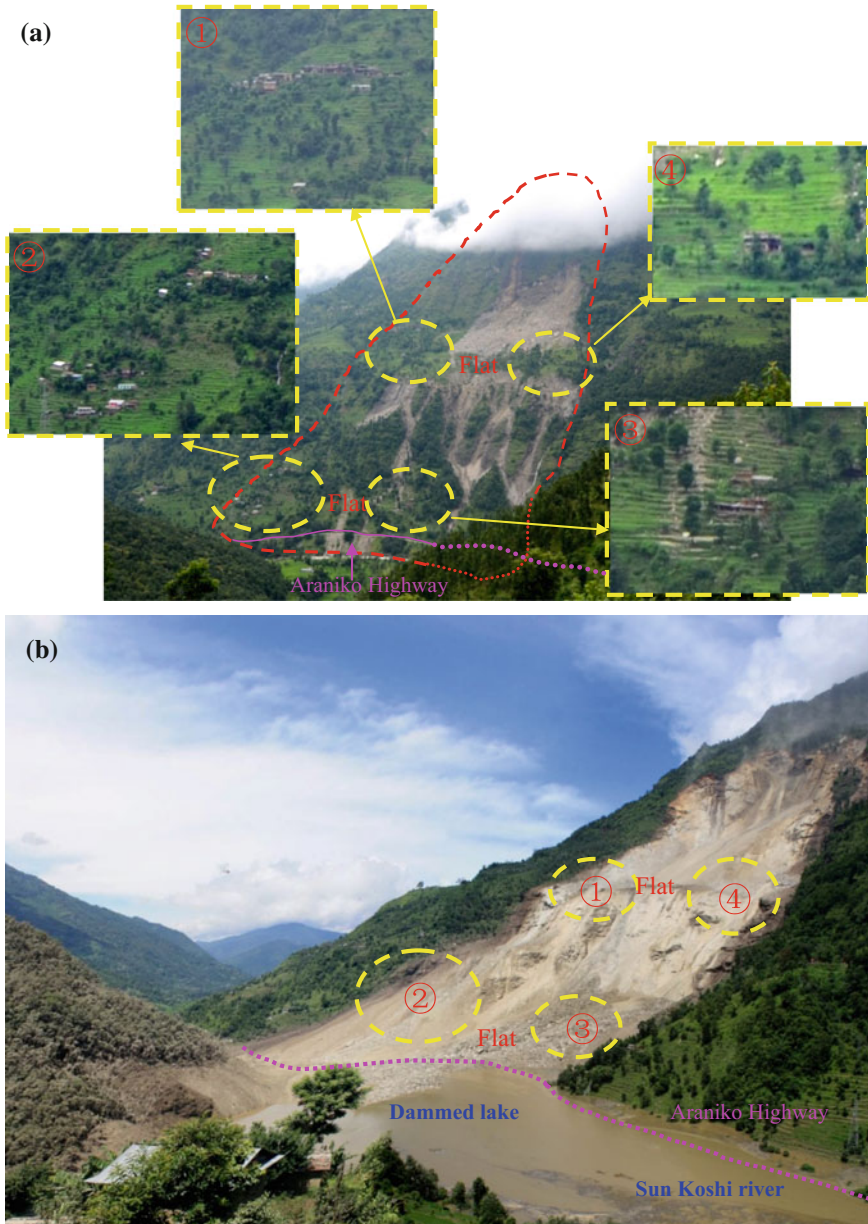


Fig. 18.10 Full view of Jure landslide in Sun Koshi River basin: **a** before landslide occurred, **b** after landslide occurred

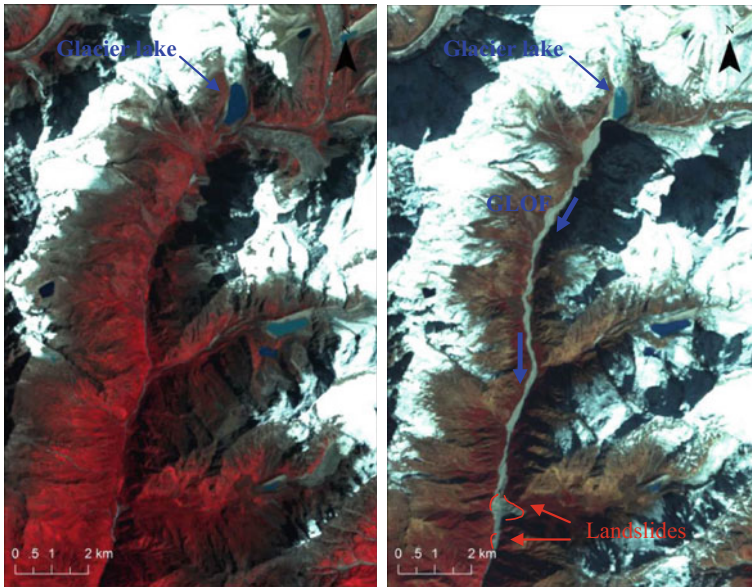


Fig. 18.11 GLOF triggers landslides in the Inkhu Khola River (Location of the glacial lake: 27° 44'35.02"N, 86°50'41.66"E)

18.5.3 GLOF-Landslide

Large-scale floods erode the banks of river or gully, which in fact accelerates instability of the banks and then triggers landslides. During the monsoon, floods occur frequently in the middle and lower reaches of Koshi River basin. Additionally, glacial lake outburst flood (GLOF) is widely distributed in the region. There are 779 glaciers with a total area of 1410 km² distributed in the Koshi River basin. The glaciers formed 599 glacial lakes covering an area of 25,958 km² so that GLOFs occurred from time to time (ICIMOD 2011). This kind of flood would always trigger landslides in the downstream. The latest GLOF occurred in the upper reach of Inkhu Khola River, a branch of the Dhudh Koshi River, triggering several landslides 11 km downstream (Fig. 18.11).

18.6 Landslide Risk Management in Trans-Boundary River Basins

Landslide risk management includes risk identification, risk assessment and risk control. Risk identification analyzes landslide patterns, characteristics and triggering factors to produce a comprehensive understanding of the hazard. Risk

assessment, the core part of risk management, includes susceptibility assessment, hazard assessment and vulnerability assessment.

Landslide susceptibility assessment is carried out by analyzing the relationship between landslide and geology, topography, climate and anthropogenic activities via statistic or physical models. Then a landslide hazard assessment can be obtained by analyzing landslide scale and frequency. The risk assessment can be performed based on hazard and vulnerability assessment. Based on the result of landslide assessment and varied levels of landslide risks, the government will be able to deploy differentiated approaches such as monitoring, engineering control or relocation to handle landslide risk (Cui 2015).

To assess landslide risks in trans-boundary river basins, concerned countries need to establish collaboration at different levels, among which sharing landslide data is crucial.

At institutional level (academic level), scientific institutes and universities are the main players. Sharing of data, information and technology should be first carried out at this level. The data include landslide formative data, landslide distribution data and economic-social data. Information about highly dangerous landslides and potentially affected victims should also be shared. However, due to technology gaps among different countries and diverse characteristics of landslides, various technology solutions may be required to cope with landslides. Technology sharing will help to optimize and enhance technical capacity of the concerned institutional parties.

At governmental level (decision-making level), each concerned country shall establish a focused disaster risk-reduction unit or agency that works closely and

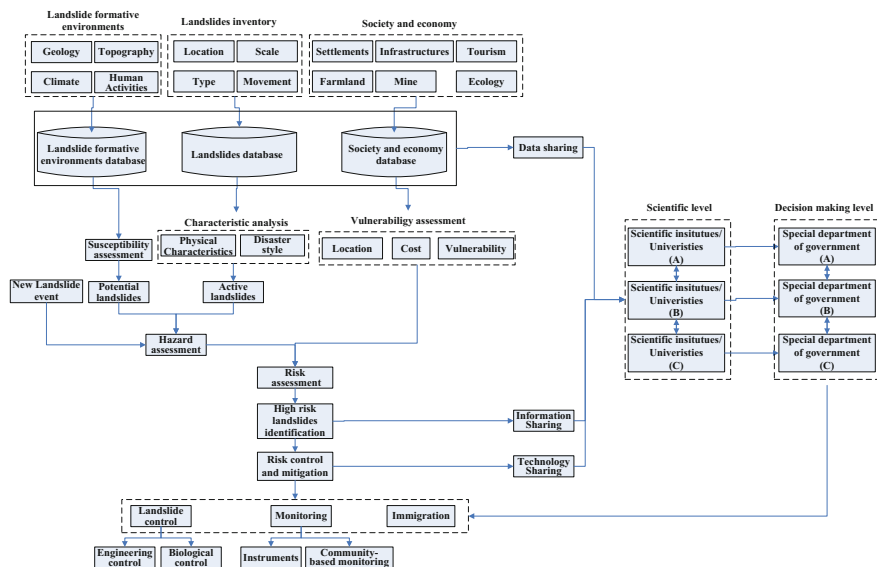


Fig. 18.12 Landslide risk management in trans-boundary river basins

directly with its own government as well as its counterparts in other countries. Research institutes can submit concerned research outcomes to such units for evidence-based policy decision on landslide monitoring, control and relocation measures. When sudden landslide happens, research institutes can timely update disaster status for government agencies to facilitate rescuing activities. When landslides lead to hazard chains that affect downstream countries, research institutes of the upstream country can submit landslide characteristic data as well as landslide risk assessment to their government through whom such information will be transferred to downstream country's government who will then quickly respond including making risk control measures and evacuating people from highly risky areas to safe places (Fig. 18.12).

18.7 Conclusion and Discussion

Koshi River basin is a representative basin for trans-boundary landslide risk management. Landslides are widely distributed in the mountainous area of the basin. According to the investigation, most of landslides supplied source material to debris flows, which happened frequently. Slopes along river are prone to landslide, and numerous landslides occurred along the river valley. Large size landslides possess risk to block the river and form dammed lakes. Besides, highway and road are also vulnerable to landslide. When they are blocked by landslides, a long time is needed to rebuild them so that life and commercial intercourse will be significantly impacted. Landslides that destroy or bury farmlands are also very common along the basin. Such farmlands are very difficult to be recovered.

Landslides seldom occur alone; sometimes they induce other hazards or are induced by other hazards. In Koshi River basin, 3 types of cascading events relate to landslide are summarized. The first type is that landslide blocks river and forms dammed lake. The break of these dams would cause flooding downstream. The second type is that landslides supply solid mass to debris flow. The third type is that flood erodes the foot of slope and trigger landslide. These cascading events make the risk extend temporally and spatially and always affect different counties. So trans-boundary risk management is an urgent need.

A preliminary framework of trans-boundary landslide risk management is discussed in this paper. The basic work is to develop landslide inventory of Koshi River basin, collect the landslide formation factors including topographic, geological and precipitation data and conduct the susceptibility, hazard, vulnerability assessment as well as risk assessment in the basin. The cooperation should be carried out at institutional level (academic) and governmental level (decision make). Universities and scientific institutes can involve in the institutional level to manage the data and information, and their task should include data sharing, information sharing and technology sharing. When trans-boundary hazards occur, information for hazards, fast assessment and disposal measures could be shared at institutional

level and then submitted to governmental level. The governments could take measures to mitigate or avoid the risk.

Acknowledgements This research was supported by the National Natural Science Foundation of China (Grant No. 41401007), the External Cooperation Program of BIC, Chinese Academy of Sciences (Grant No. 131551KYSB20130003) and the External Cooperation Program of BIC of Chinese Academy of Sciences (Grant No. GJHZ20132). This study was also jointly supported by the Australian Government funded Koshi Basin Programme at ICIMOD as well as ICIMOD's core funds contributed by the governments of Afghanistan, Australia, Austria, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Norway, Pakistan, Switzerland and the UK.

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