Chapter 4

Flash Flood Risk Assessment

Risk assessment forms the core of the flash flood risk management process. Risk assessment helps identify potential risk-reduction measures. If integrated into the development planning process, it can identify actions that both meet development needs and reduce risk. Flash flood damage can be reduced by establishing a proper flood control management structure or organ to manage flood events and reduce their negative effects. The benefits of precautionary steps, measures, and actions will bring communities, agricultural land, infrastructure, and livelihoods in flash flood-prone areas to safety with the help of government management.

4.1 What is Risk?

The term *risk* has a range of meanings depending on the specific sector in which it is used — for example, the economic, environmental, or social sector. Because the terminology of risk has been developed across a wide range of disciplines and activities, there is potential for misunderstanding of the technical terminology associated with risk assessment, as technical distinctions are made between words which in common usage are normally treated as synonyms. Most important is the distinction that is drawn between the words *hazard* and *risk*.

This manual uses the Source-Pathway-Receptor-Consequence (S-P-R-C; Figure 22) concept proposed by Gouldby and Samuals (2005): For a risk to arise there must be hazard, which is the source or initiator event (e.g., cloudburst); pathways between the source and receptors (e.g., flood routes, overland flow, or landslide); and receptors (e.g., people and property). The consequence depends on the exposure of the receptors to the hazard.

The evaluation of risk requires consideration of the following components: the nature and probability of the hazard (p); the degree of exposure of the receptors (number of people and property) to the hazard (e); the susceptibility of the receptors to the hazards (s); and the value of the receptors (v).

Therefore

$$\text{Risk} = f(p, e, s, v)$$

The first two components of risk are related to hazard and the last two components to vulnerability. In the functional form,

$$\text{Vulnerability} = f(s, v)$$

Thus, vulnerability is a sub-function of risk. This term describes the predisposition of a receptor to suffer damage.

Risk is, therefore, a statistical concept and is the probability that a negative event or condition will affect the receptor in a given time and space. Thus, risk can be understood in simple terms as:

$$\text{Risk} = (\text{Probability}) \times (\text{Consequence})$$

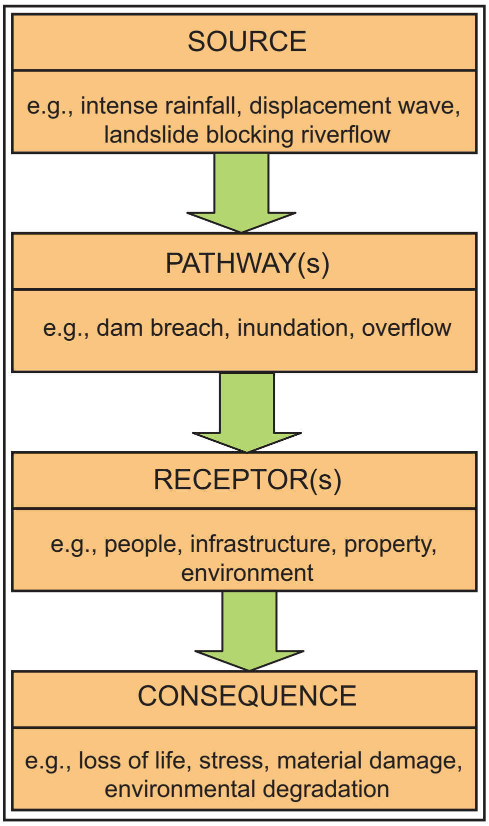


Figure 22: Source-Pathway-Receptor-Consequence conceptual model

The degree of flood hazard in an area is often measured by the return period of the flood, which relates to the probability of the flash flood hazard. Management of flash flood risk can be accomplished by managing hazard, exposure, and vulnerability. Here vulnerability encompasses both physical and social vulnerabilities. Flash flood risk management can be done through structural measures, which alter the frequency (i.e., the probability) of flood levels in the area. On the other hand, flash flood management can also be done through non-structural measures that focus on the exposure and vulnerability of a community to flash flood. Changing or regulating land use, installing an early warning system, and developing the community's resilience are examples of non-structural measures.

4.2 Major Steps in Flash Flood Risk Assessment

Risk assessment forms the core of the disaster risk management process and results in the identification of potential risk-reduction measures. Risk assessment integrated into the development planning process can identify actions that both meet development needs and reduce risk. Identified risk-reduction actions can be incorporated into development policies and legal arrangements. For example, policies and associated laws and regulations to reduce the risk of flash floods can require or encourage construction of spurs or embankments as part of road or water resources projects.

Risk assessment is an essential part of the flash flood risk management decision-making process. A number of methods have been developed to assess the risk of natural disasters. Here, we have adopted the method developed by Colombo et al. (2002), and Gouldby and Samuals (2005), after appropriate modification (Figure 23). Risk assessment steps include:

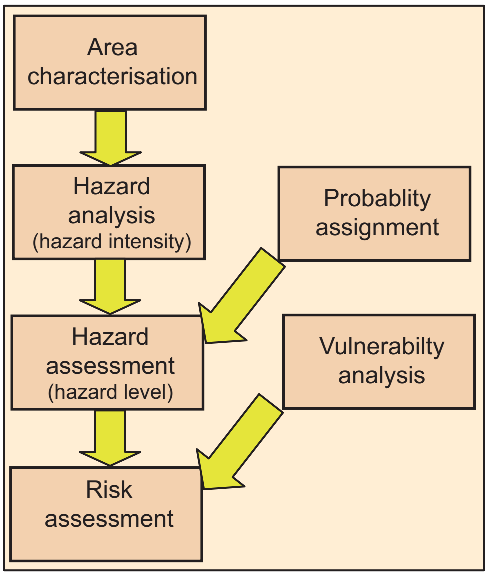


Figure 23: Procedural diagram for flash flood risk analysis

1. characterising the area
2. assessing hazard or determining hazard level and intensity
3. assessing vulnerability
4. assessing risk

4.3 Characterisation of the Risk-prone Area

This process comprises three main topics: the information to be collected on the area prone to flash floods; the tools to be used for collection, processing, and archiving the information; and the format for documentation.

Information to be collected

The information to be collected to characterise a flash flood-prone area must fulfil two main tasks: it must provide scientific data for hazard, vulnerability, and risk analysis, and it must assist decision-makers during the subsequent planning process. Characterising the area is important for both hazard and vulnerability assessment. For this, the following information should be collected.

- **Geography (physical and social):** for example, the length of river sections, communities/provinces involved, peculiarities of the area, and population and population distribution
- **Geology and geomorphology:** the properties of rocks and soil in the area, river courses or pathways
- **Hydrology and hydraulics:** the properties of the rivers and waterways in the area such as flow amount, cross-sections, and slope
- **Hydrometeorology:** for example, air temperature, annual precipitation, months of maximum and minimum precipitation, values of precipitation extremes

- **Vegetation:** types of plants and trees that grow in the area
- **Land use:** land use types such as agricultural land, forest and other wooded land, built-up and related land, wet open land, dry open land with special vegetation cover, open land with or without significant vegetation cover
- **Existing counter-measures:** for example, check dams and bioengineering work
- **Historical analysis of local flood events:** for example, floods that have happened in the past; sources of information include local memory, damaged environment, national and local databanks, newspapers, and interviews with victims

Tools for collecting, processing and archiving information

Three main tools are useful in characterising the area subject to flash floods:

1. database for storing general information
2. a geographic information system (GIS) for graphical representation of maps and spatial analysis
3. a set of computer programs for data processing (e.g., hydrological and hydraulic models)

Format for documentation

Flash floods in the HKH region are generally spatially limited and often occur in remote and isolated locations, frequently going undocumented. Even documented events often lack information vital for risk analysis. Thus, it is extremely useful to develop a comprehensive standardised format to facilitate further analysis of data. Such a format will enhance information sharing among institutions, communities, and countries in the region. Event documentation should include the following information:

- **Location of the event:** geographic coordinates of settlements in the vicinity of the source, as well as the impacted areas
- **Basin details:** description of the drainage system, the river/stream where the event occurred, the major river basin that the river/stream drains into
- **Cause of event:** heavy rainfall, GLOF, LDOF, etc.
- **Hydrometeorological details:**
  - amount and duration of rainfall including peak hourly intensities
  - amount of water released by LDOF or GLOF
  - duration of flood
  - peak flood discharge
- **Extent of damage:**
  - dead
  - injured
  - missing
  - agriculture
  - infrastructure
  - homesteads
  - businesses
  - cattle
  - affected area, people, families
- **Damage in monetary terms**

4.4 Hazard Analysis

This process includes defining flash flood hazard intensity (the strength of the flash flood), and describing alternative scenarios in their catchments. Determining hazard intensity is a step towards determining hazard levels. It is common to present hazard scenarios in the form of hazard maps. Modern technology has advanced hazard mapping and the prediction of future events considerably through techniques such as geological mapping and satellite imagery, production of high resolution maps, and computer modelling. New geographic information system (GIS) mapping techniques, in particular, are revolutionising the capacity to prepare hazard maps. It is, however, essential to verify the maps through field observation. Often hazard maps can be prepared with community involvement, and the best results can be achieved by combining the technical hazard maps with others prepared by the community. This process includes defining flash flood hazard intensity and possible scenarios in their catchments. A simple way of assigning flash flood hazard intensity is shown in Table 3, although in reality determining hazard intensity is much more complicated. Alternatively, hazard intensity can be determined by the level of anticipated flooding. Figure 24 shows an example of a flood hazard map.

Table 3: **A simple way of assigning hazard intensity**

Hazard intensity	Danger to population close to the stream	Danger to population in settlement (about 500m from the stream)	Danger to population 1 km away from the stream	Danger to population more than 1 km away from the stream
High	yes	yes	yes	yes
Moderate	yes	yes	yes	no
Moderately Low	yes	yes	no	no
Low	yes	no	no	no

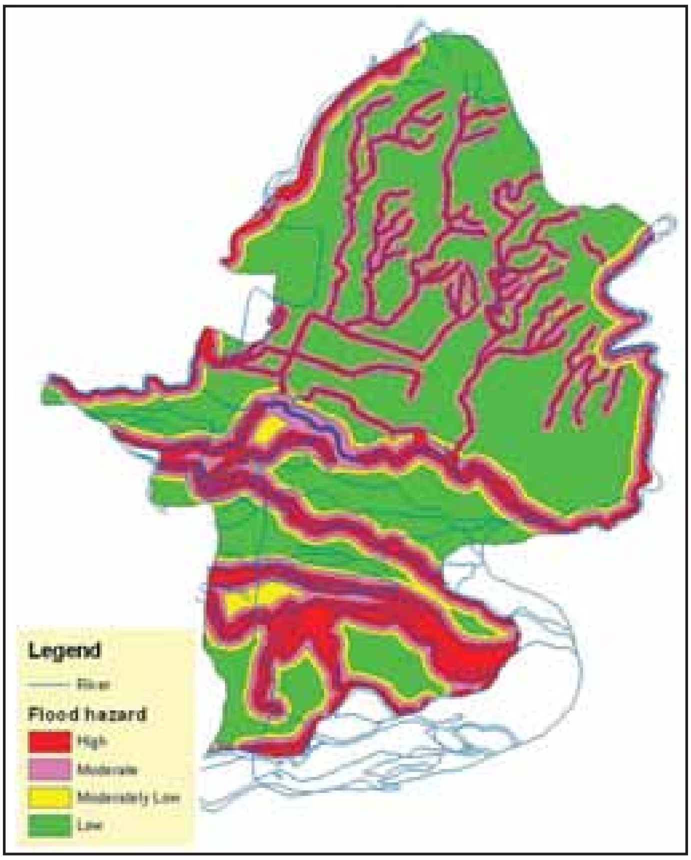
Assigning probability to a hazard scenario

The hazard scenario should be assigned probability levels. In the case of intense rainfall floods, the return period or frequency of the rainfall events, or the return period or frequency of flooding caused by these events, can be used to give probability levels as shown in Table 4.

It is difficult to assign probability levels to other types of flash floods such as LDOF and GLOF, as they often occur only once. In such cases it is customary to use probability levels based on the characteristics of the lake, dam, or surrounding environment, as shown in Table 5.

4.5 Hazard Assessment

Hazard assessment includes determining the hazard level scale by combining the hazard intensity based on the hazard intensity scenario and the hazard probability level. Figure 25 shows an example of a hazard level scale. The hazard probability has four levels and the hazard intensity level has four degrees (high, moderate, moderately low, low). The resulting 16-cell hazard level scale identifies four different levels (very high, high, moderate, and low).



Source: ICIMOD

Figure 24: A simple flood hazard map of Bhandara Village Development Committee area, Chitwan, Nepal

Table 4: **Probability level of a hazard scenario**	
Probability level	**Frequency**
High	at least once in 10 years
Moderate	once in 10 to 30 years
Moderately Low	once in 30 to 100 years
Low	less frequent than once in 100 years

Table 5: **Probability level for LDOF and GLOF**		
Indicator	**Characteristic**	**Qualitative probability**
Type of dam	ice	high
	moraine	medium high
	bedrock	low
Freeboard relative to dam	low	high
	medium	medium
	high	low
Dam height to width ratio	large	high
	medium	medium
	small	low
Impact waves by ice/rock falls reaching the lake	frequent	high
	sporadic	medium
	unlikely	low
Extreme meteorological events (high temperature/ precipitation)	frequent	high
	sporadic	medium
	unlikely	low
Source: RGSL (2003)		

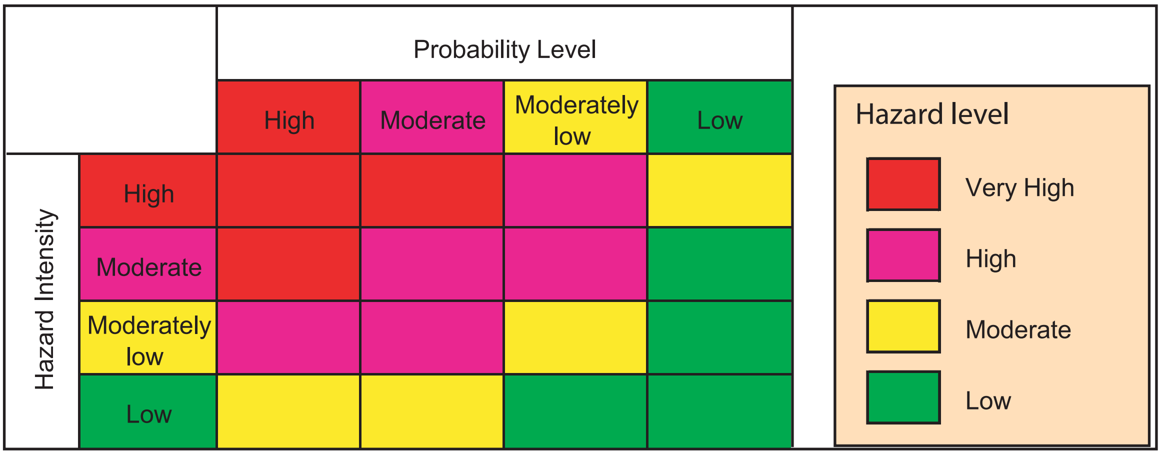


Figure 25: Hazard level scale

4.6 Vulnerability Assessment

The next step in risk analysis is the vulnerability assessment. There are three schools of thought on vulnerability analysis. The first focuses on exposure to biophysical hazards, including analysis of the distribution of hazardous conditions, human occupancy of hazardous zones, degree of loss due to hazardous events, and analysis of the characteristics and impacts of hazardous events (Heyman et al. 1991; Alexander 1993; Messner and Meyer 2005). The second looks at the social context of hazards and relates social vulnerability to coping responses of communities, including societal resistance and resilience to hazards

(Blakie et al. 1994; Watts and Bohle 1993; Messner and Meyer 2005). The third combines both approaches and defines vulnerability as a hazard of place, which encompasses biophysical risks as well as social response and action (Cutter 1996; Weichselgartner 2001; Messner and Meyer 2005). The third school has become increasingly significant in the scientific community in recent years and this manual is based on this approach.

Physical vulnerability assessment

Physical vulnerability is expressed as a vulnerability index that is a function of susceptibility and exposure.

Susceptibility

Susceptibility is the state of being easily influenced by flash flood hazards. Those elements susceptible to flash flood hazard are called elements at flash flood risk. Susceptibility can be expressed in terms of a vulnerability index, which can be in monetary or non-monetary units. Generally, high-value elements are given a higher vulnerability index. It is difficult to quantify some elements at risk, including human lives, ecological species, and landscapes; thus, a vulnerability index must be based on qualitative categories. Table 6 gives a general guideline for assigning vulnerability levels to different land use categories.

Table 6: **Vulnerability level scale as a function of land use categories**

Category	Vulnerability level
Natural areas (e.g., natural water courses, unproductive areas, and so on)	Low
Agriculture and forestry (e.g., meadows, pastures, forests)	Moderately low
Special agriculture (e.g., fields, orchards)	Moderately low
Local infrastructure (e.g., trails, secondary roads, tertiary canals)	Moderately low
Trade and industry	High
National infrastruture (e.g., main roads, railway lines, main canals)	High
Settlements	High
Special objects (e.g., power stations, cultural heritage sites, strategic facilities)	High
Source: RGSL (2003)	

Exposure

The vulnerability index also depends on the exposure of the element at flash flood risk. Exposure refers to the type, extent, and magnitude of susceptible elements likely to be affected when a flash flood occurs. The exposure indicator depends on the proximity of the susceptible element to the river, river morphology, geology of the location, elevation, return period of the flood, flow velocity, and so on. Exposure can be evaluated in monetary terms and expressed in qualitative categories (e.g., high, moderately high, moderate, low, etc.).

Socioeconomic vulnerability assessment

Socioeconomic vulnerability is a function of the society's adaptive capacity in a physically vulnerable zone. This adaptive capacity is a function of social and economic processes. New settlements along riverbanks or flash flood debris fans are examples of processes that increase vulnerability to flash flood. Poverty and limited availability of land are governing factors behind this. Areas with access to communications, financial institutions, and markets, and having diversified income sources have a stronger adaptive capacity and are, hence, less vulnerable. Adaptive capacity can be expressed quantitatively or qualitatively. Some quantitative and qualitative indicators are listed in Table 7. The quantitative indicators have to be converted to qualitative categories so that they can be combined with qualitative indicators to derive the socioeconomic vulnerability of the area of interest.

Physical and socioeconomic vulnerability are combined to obtain the total vulnerability, which might again be presented as qualitative categories (high, moderate, moderately low, low, and so on).

Table 7: **Quantitative and qualitative indicators**	
Parameter	**Quantitative indicators**
Accessibility	Road density (m/km^2)
Health	Number of health institutions/1000 population
Communications	Number of telephones/1000 population
Institutions	Number of GOs and NGOs/1000 population
Economic	Number of financial institutions/1000 population
Loss-sharing measures	Value of revolving fund (disaster fund)
Economic diversity	Percentage of families with a number of income sources
Qualitative indicators	
Emergency facilities	
Warning system	
Loss reduction measures	
Awareness and attitude	
Source: Shrestha (2005)	

4.7 Risk Assessment

A risk-level scale is a combination of hazard level and total vulnerability (both physical and socioeconomic). The scale is obtained by subjective judgment, similar to the hazard-level scale. Figure 26 shows a risk-level scale that can be used to assess flash flood risk. Four levels of hazard and four levels of total vulnerability (high, moderate, moderately low, and low) are considered. The resulting risk-level scale consists of 16 cells and may be classified into five different risk levels: very high, high, moderate, moderately low, and low.

The methodology presented in this section is one of many available in the literature or, rather, it is a combination of several methodologies. It may be modified or simplified according to need, resources available, and data available. Annex 1[6] provides an exercise on hazard vulnerability and risk assessment. The ILWIS[7] 3.2 based exercise uses multiple hazards instead of a single hazard. In reality, communities are exposed to different types of hazards and stresses.

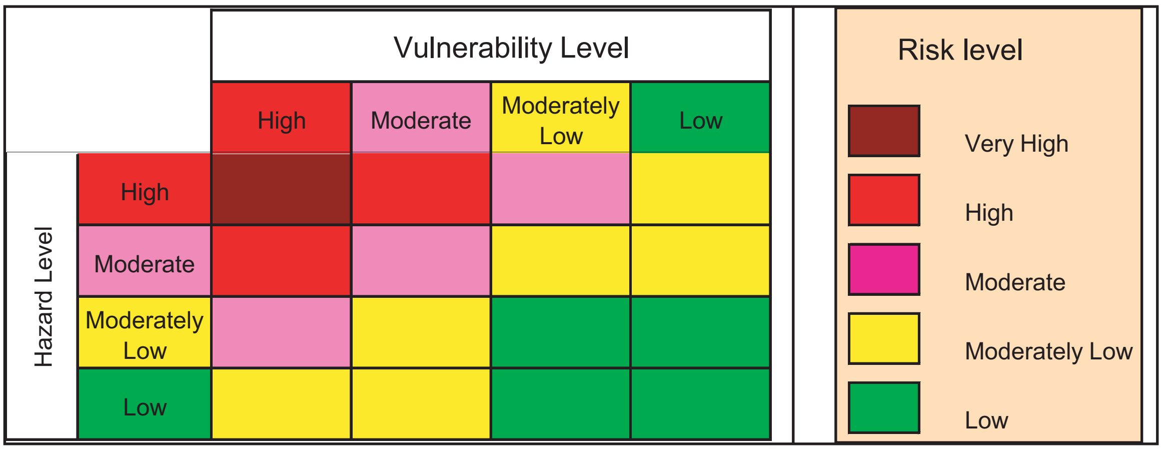


Figure 26: Classification of risk level

[6] The exercise was provided by C.J. van Westen, International Institute for Geo-Information Science and Earth Observation (ITC) and is available from <http://www.itc.nl/ilwis/applications/application01.asp> (Accessed October 2007).
[7] An open source version, ILWIS 3.4 Open, can also be used. It is freely downloadable from <http://52north.org/index.php?option=com_projects&task=showProject&id=30&Itemid=127>.