SRC International Cooperation

Risk and Cost-Benefit Analysis

Methodological Guide for Risk Analysis and Cost-Benefit Analysis of Mitigation Measures

Swiss Red Cross

Why this guide is necessary?

This guide explains in a practical way the procedure for a cost-benefit analysis of mitigation measures and provides a calculation tool.

The Swiss Red Cross (SRC) supports its partner organizations in their disaster risk reduction programmes aiming at strengthening the resilience of vulnerable people and communities. This includes emergency response, recovery and risk prevention/mitigation activities. The SRC's approaches are described in institutional concept documents, such as the Disaster Risk Management Policy and the concept of disaster risk reduction. An important component is the implementation of mitigation measures for disaster risk reduction. When mitigation measures are planned, there are often conflicts of interest regarding the need for and affordability of mitigation measures, as shown in the example below.

On February 6, 2018, the urban area of the municipality of Tiquipaya (Bolivia) was affected by a significant debris flow. Four people were killed and about 200 buildings were destroyed or damaged.

Illustration 1: Buildings destroyed and damaged Tiquipaya, Bolivia. Source: Los Tiempos.

The hazard map in Illustration 2 shows the potential area, return period, and intensity of future debris flow events in Tiquipaya. It indicates that corresponding or even greater events can be expected in the future.

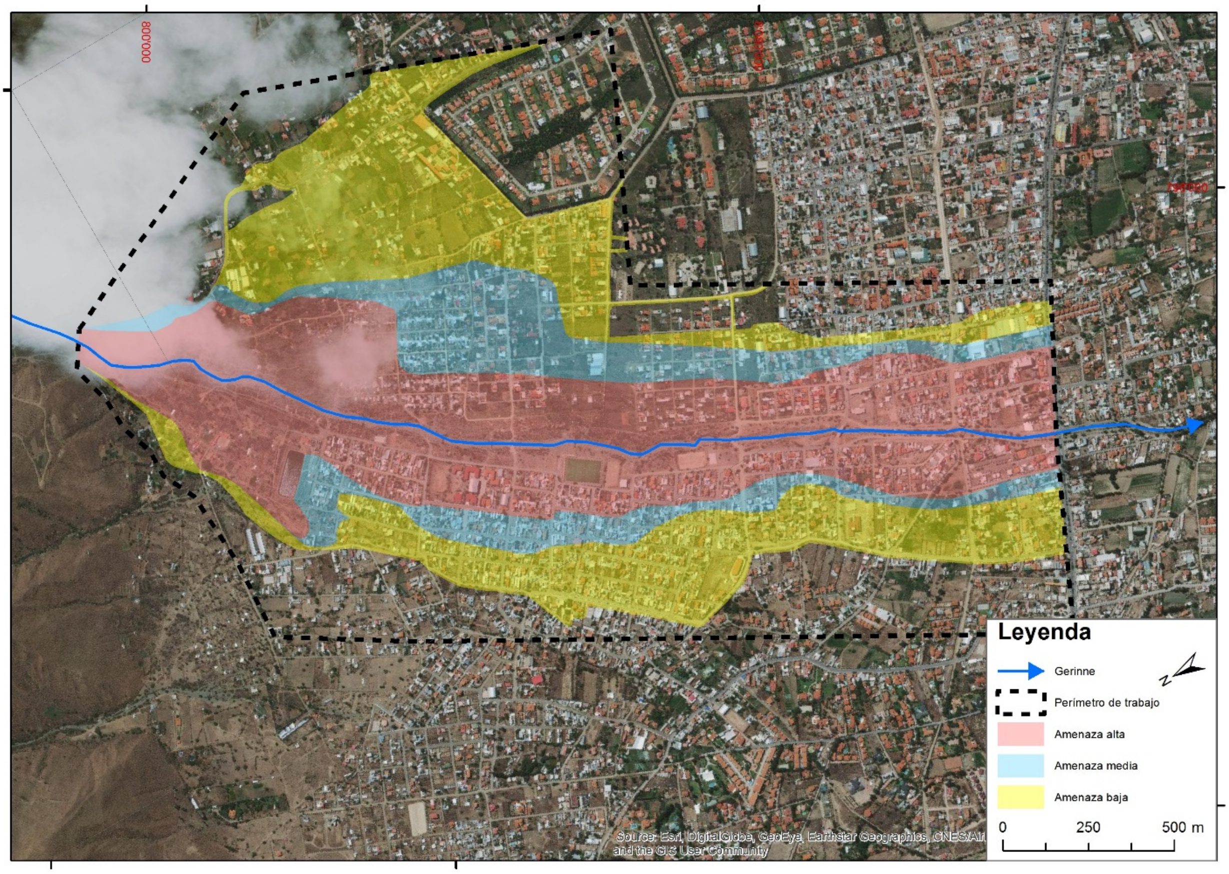

Illustration 2: Hazard map of Tiquipaya, Bolivia. Details of the different hazard levels are explained in the methodological guide “Natural Hazard Analysis”. Source: Geotest AG.

From the point of view of the affected population in Tiquipaya, there is a great need for mitigation measures to protect the population from future debris flows. Limited resources force financial authorities to prioritize areas for planning and implementing mitigation measures. Prioritization is based on the following key questions:

Are the damages which can be expected in the future tolerable?

Are investments in mitigation measures justified?

The following criteria are used as a basis for prioritization:

- Hazard map (affected area, frequency and intensity of future events)
- Number and localization of people and livelihoods at risk (buildings, infrastructure, economic areas)
- Vulnerability of people and their livelihoods
- Capacity of the endangered population to avoid damage
- Costs and impact of possible mitigation measures
- Lifetime of mitigation mesaures

As a result of subjective interpretation of the key questions and prioritization criteria, conflicts of interest often emerge between financial actors and the affected population. To avoid such conflicts, a systematic methodology is required to assess the need for and cost-effectiveness of mitigation measures.

This guide describes a standard procedure for cost-benefit analysis, through which the potential damage and the cost-effectiveness of mitigation measures can be objectively quantified.

Target groups for the application of the Guide

The guide is aimed at decision-makers in planning and implementing mitigation measures (authorities at all governmental levels and Red Cross and Red Crescent [RC/RC] project managers). The guide serves as a tool for the RC/RC to support its partners in planning mitigation measures. The presentation of cost-effective measures is an important advocacy tool.

Once the necessary baseline data is available (hazard mapping and technical planning of mitigation measures), no specific expertise is required for the operational application of the guide.

Possibilities and limits of the Guide

This methodology for cost-benefit analysis of mitigation measures can be applied to flood, debris flow, landslide and rockfall processes. It can also be used for other hazardous processes. For this purpose, however, the calculation tools (Annex) on which the guide is based should be extended accordingly. The methodology allows for the cost-effectiveness assessment of both structural and organizational measures to reduce disaster risks.

The calculation tools are free and easy to use. Therefore, the cost-benefit assessment can also be carried out by non-specialists.

The guideline offers two tools for calculating the risks and cost-effectiveness of protective measures. The first is the WebGIS application "MiResiliencia". This is suitable for both rural and urban areas, for structural as well as green measures and for organizational measures. "MiResiliencia" was developed by the Swiss Development Cooperation (SDC) and is now used in several countries. The other tool option consists of an Excel file. This offers the possibility that all calculation parameters can be adapted by the users themselves to the specific conditions in the country. The disadvantage of the Excel solution is the lack of spatial reference for the individual objects in the risk calculation. In terms of the calculation methodology, the two tools are identical.

Risk approach

In order to rationalize the investment in a mitigation measure, it is important to know whether the benefit of the measure exceeds costs.

The so-called "risk approach" is used to measure the **benefit** of the measures. Risk describes the potential damage (direct and indirect damage) to people and their livelihoods, which can occur over a certain period of time. Risk depends on the hazard, on the vulnerability of people and their livelihoods, but also on their ability to avoid possible damage. In this context, the International Federation of Red Cross and Red Crescent Societies (IFRC) uses the following basic equation:

$$Risk = \frac{\text{Hazard} * \text{Vulnerability}}{\text{Capacity}} \quad \text{[\$/year] or [fatalities/year]}$$

In risk assessment, it applies the principle that the greater the hazard and vulnerability of the population and its livelihoods, the greater the risks. By contrast, risk is reduced by the population's ability to avoid damage. Risk is quantified as the probable loss per year.

The benefit of a measure is quantified by the risk difference with and without the planned measures.

$$Benefit = Risks \;\; \text{without} \, measures - Risks \; with \; measure \; planned$$

The **costs** of a measure are made up as follows:

- Construction costs/establishment of a mitigations measure (reduced by the value remaining after its lifetime)
- Maintenance costs of the measure
- Bank interest costs

Because a mitigation measure has limited effect duration, the costs are related to its lifetime, from which it is possible to determine its annual costs.

A risk reduction, i.e. the benefit of a mitigation measure, will be compared with the annual costs of the measure, thus determining the cost-benefit ratio. If the benefit of the measure exceeds the costs, the measure is considered to be cost-efficient and its implementation is recommended.

$$Measure\ cost - efficiency = \frac{Risk\ without\ mesure - Risk\ with\ measure}{Annual\ cost\ of\ measure}$$

Readers already acquainted with the mathematical basis of risk can go directly to the chapter "Working Steps for a Cost-Benefit Analysis". Otherwise, it is advisable to read the following chapter entitled "Principle of Risk Calculation".

Principle of Risk Calculation

Risks are estimated individually for each object under hazard (so-called "damage potential"). For example, an object is a building where people live, an infrastructure facility or a working area (e.g. a piece of crop land). Three risk categories are calculated for each object and the risks of the three characteristics are added to the overall risk per object:

1) People at risk due to direct damage (damage during the event) → RPD

2) Assets at risk due to direct damage (damage during the event) → RAD

3) Assets at risk due to indirect damage (damage resulting for the object) → RAI

Illustration 3 shows a flood hazard map. On the upper side of the river there is a risk for 15 buildings in the hazard area. On the lower side of the riverbed there is a flood hazard as well, but no risk because there are no objects in the hazard area. For each of the 15 individual objects, the three risk characteristics can be quantified in financial terms.

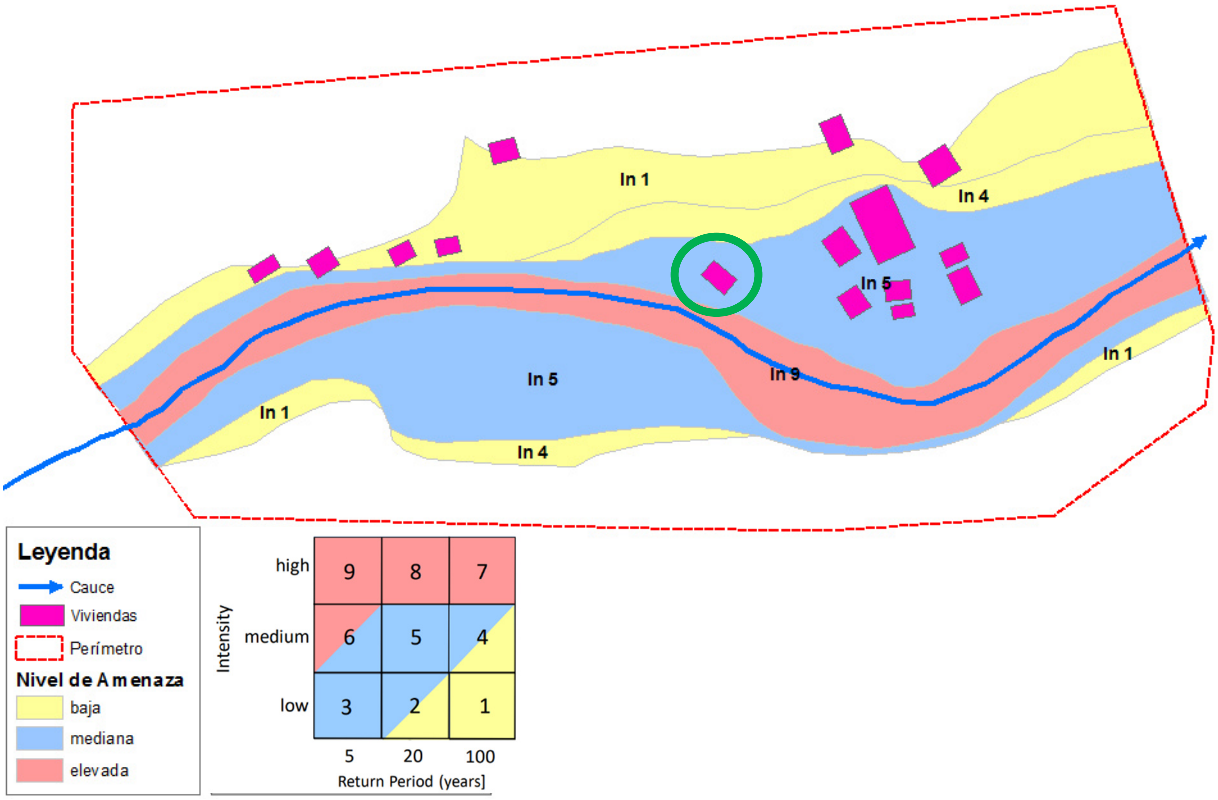

Illustration 3: Hazard map for a "flood" process. The intensity and return period of the floods are indicated by indices according to the 9-field matrix.. The concept of hazard classification is documented in the "Natural Hazard Analysis" guide.

Calculation of the direct damage risk for people (RPD)

People in buildings: $RPD = pSO * MO * NP * WP * p\mathrm{Pr}/30$ [$/a]

Calculation of the direct damage risk for assets (RAD)

Buildings: $RAD = pSO * VF * BV/30$ [$/a]
Roads: $RAD = pSO * VF * RV * L/30$ [$/a]
Agriculture: $RAD = pSO * VF * CrV * A/30$ [$/a]

$\boldsymbol{RPD20}$	$\boldsymbol{People\ at\ risk\ for\ a\ 30\ yearly\ scenario, direct\ damage}\ [\$/\boldsymbol{a}]$
$\boldsymbol{RAD20}$	$\boldsymbol{Assets\ at\ risk\ for\ a\ 30\ yearly\ scenario, direct\ damage}\ [\$/\boldsymbol{a}]$
$\boldsymbol{VF}$	$\boldsymbol{Physical\ vulnerability}\ [-]$
$\boldsymbol{BV}$	$\boldsymbol{Building\ value}\ [\$/\boldsymbol{unit}]$
$\boldsymbol{RV}$	$\boldsymbol{Road\ value}\ [\$/\boldsymbol{m'}]$
$\boldsymbol{CrV}$	$\boldsymbol{Crop\ value\ per\ ha}\ [\$/\boldsymbol{ha}]$
$\boldsymbol{L}$	$\boldsymbol{Length\ of\ exposed\ road}\ [\boldsymbol{m}]$
$\boldsymbol{A}$	$\boldsymbol{Exposed\ area}[\boldsymbol{ha}]$
$\boldsymbol{MO}$	$\boldsymbol{Mortality}\ [-]$
$\boldsymbol{NP}$	$\boldsymbol{Number\ of\ people\ within\ the\ same\ object}$[-]
$\boldsymbol{p}(\boldsymbol{Pr})$	$\boldsymbol{Probability\ of\ presence}[\boldsymbol{hours\ a\ day}]$
$\boldsymbol{WP}$	$\boldsymbol{Willingness\ to\ pay}[\$]$
$\boldsymbol{pSO}$	$\boldsymbol{Probability\ of\ spacial\ ocurrence}$ [-]

Notes on risk factors

FV: Physical vulnerability describes the probability of a building and its furniture being destroyed. The value is between 0 (no vulnerability) and 1 (complete destruction is expected). The FV value depends on the type of building, the hazard process (e.g. flood) and its intensity. In the case of low intensity floods, the value of the FV factor for buildings is close to zero. For high intensity floods, the value is close to 1. The vulnerability values are taken from the experience of several countries.

BV/RV/CrV: These parameters include costs for the restoration of destroyed buildings, roads and crop land. In the risk analysis, default values per object type are used. These must be defined for each country or region together with the authorities.

MO: Mortality describes the probability of death, i.e. the probability that a person dies in a building during a given scenario (e.g. medium intensity flood event). The MO value is between 0 (no probability of death) and 1 (an individual is certain to die in the scenario under consideration). The MO value depends on the type of building, the type of hazard (e.g. flood), its intensity and the possibility of people being able to escape. In hospitals, for example, the possibility of escaping is less than in a school building. The mortality value is always lower than the FV value. Mortality values are based on the experience of several countries.

pPr: The probability of presence describes the number of hours per day that people are present in a building. It is also determined using standard values that the authorities decide on for each building type.

WP: "Willingness to pay" represents society's monetary will to avoid a death. The value depends on a country's economic conditions. The value is based on a participatory process with authorities. One concept to determine value is based on the assessment of a person's average income over his/her working life. It is calculated by multiplying the annual income by the number of years of employment, starting from the average age of the population to the normal national retirement age. If informal work is also relevant, it should be added to the total. No difference between age, sex and origin of people is allowed.

pSO: It is assumed that a future event scenario does not affect the whole area of a hazard map for the corresponding scenario. The probability of spatial occurrence (pSO) indicates the percentage of the event scenario area considered in relation to the hazard map area for this scenario. According to experience, the pSO average is 0.5 for floods, 0.4 for debris flows and 0.2 for slope-type debris flows. Standard values are recommended in the risk calculation tool in Annex, but the user can modify them manually.

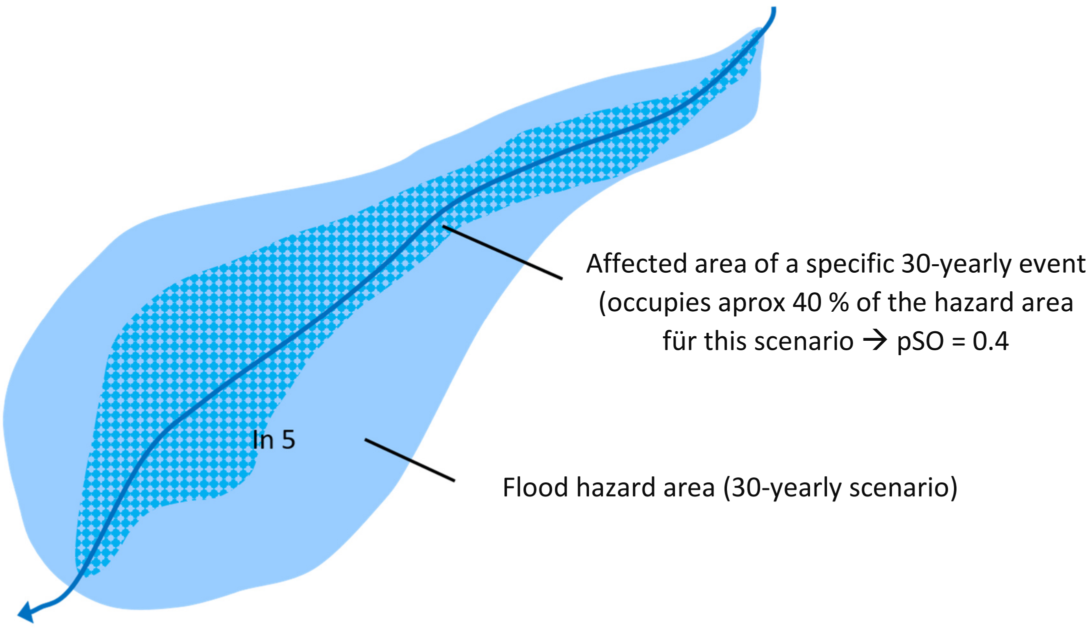

Illustration 4: Visualization of the concept of the spatial probability factor (pSO).

Calculation of indirect damage risks (RAI)

Indirect damage risks are quantified on the basis of long-term economic income lost in the event of a disaster. For each revenue-generating object type (administration building, hospital, crop area...), a reference downtime in days is defined depending on the type and intensity of the hazardous process (e.g. "flood, medium intensity"). This downtime is multiplied by the average daily financial loss of the object type.

Downtime is reduced by a capacity factor. This factor is determined by means of an extensive catalogue of criteria, in which the capacity factor represents the weighted average value of all the partial capacity criteria. The annex provides an overview of the capacity criteria and a recommendation for their quantification.

$$RAI = DP * pOE * DEL * (1 - CAP)$$

DP	*Days of inactivity*	[days]
pSO	*Probability of spatial occurrence*	[-]
DEL	*Dayly economic loss*	[$/day]
CAP	*Capacity factor*	[-]

The RPD, RAD and RAI risk values are added up to obtain the total risk per object. In addition, the accumulated risks of all objects are added up, thus determining the overall risk for the situation with or without planned measures,

$$Rtotal = \sum_{k=1}^{i} (RPD + \mathrm{RAD} + \mathrm{RAI})$$

where "i" comprises the number of objects at risk that are within the influence of the planned measure.[1]

[1] The risk calculation based on the hazard map takes into account the fact that the same objects can be affected in different scenarios (different return periods) and that the hazard map only represents the highest applicable hazard level. An algorithm allows for risk calculations for all hazard scenarios affecting an object.

Working steps of a cost-benefit analysis

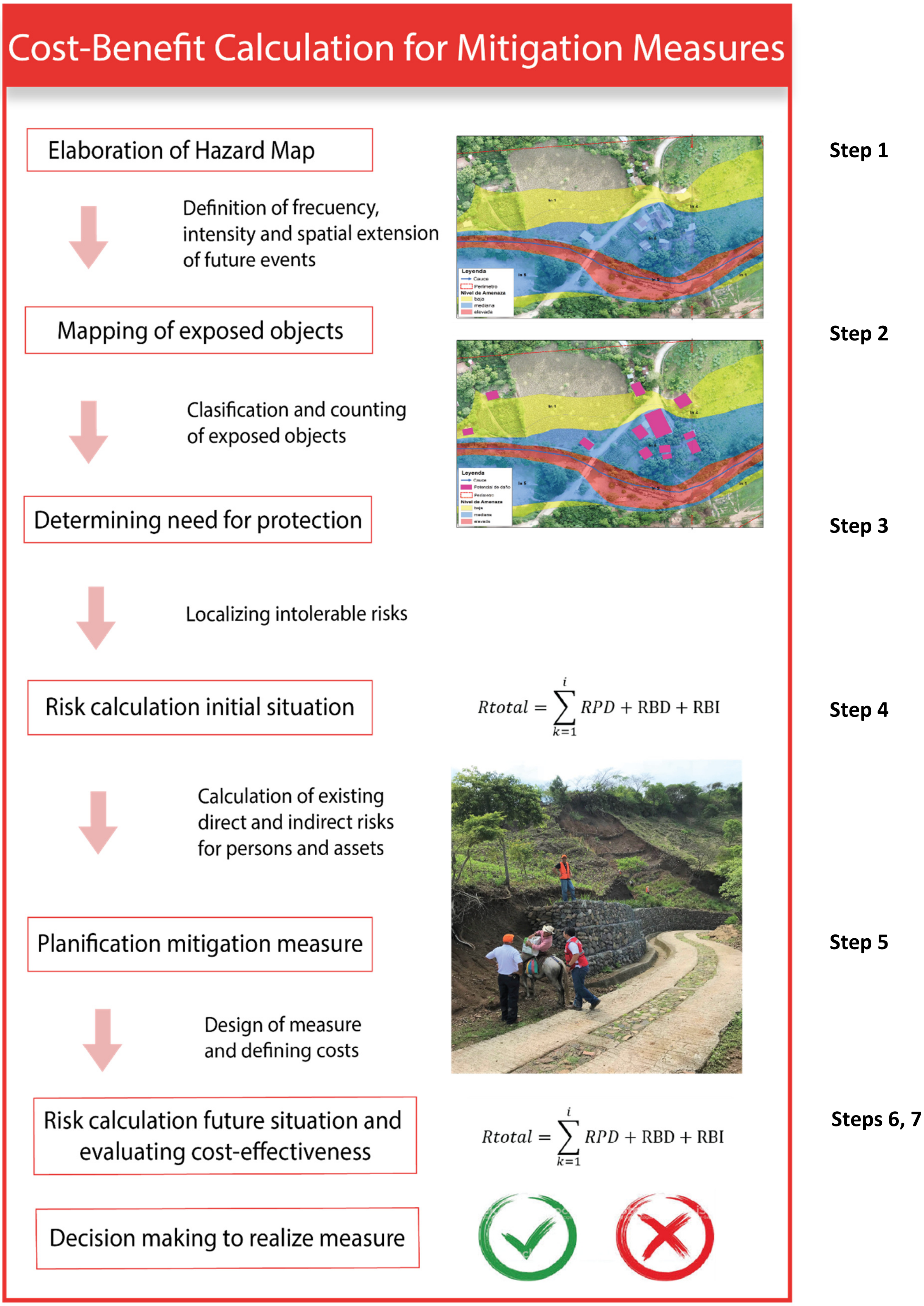

Illustration 5: Working steps for a risk assessment and cost-benefit analysis of mitigation measures.

Step 1: Preparation of the hazard map

The authorities or the Red Cross partners prepare a hazard map for a defined area. The Swiss Red Cross methodological guide entitled “Natural Hazard Analysis” describes the necessary steps for the “flood”, “debris flow”, “slope-type mud flow”, “permanent landslides” and “rockfall” processes. The hazard map is essential for the cost-benefit analysis.

Step 2: Mapping the potential damage

On a copy of the hazard map, all relevant livelihoods (buildings, agricultural areas and infrastructure facilities) are recorded as points, lines or areas classified according to types of potential damage and numbered consecutively. Table 1 shows an example of a classification of the types of damage potential. For each type, average values are defined for restoration costs, people' occupation and time spent per day (in hours).

Table 1: Example of a list of types of damage potential for risk analysis. Classification should be defined by decision-makers. In MiResiliencia, the values are already predefined, but most of the values can be adjunsted by the user himself. In the Excel-Sheet, all values can be modiified by the user himself/herself.

	Value per unit	**# people**	**Hours staying**
Type of damage potential	*$*	*# people*	*hours*
Wooden and/or adobe house	$/unit	# people	# hours
Brick house	$/unit	# people	# hours
Standard school (concrete walls)	$/unit	# people	# hours
Church	$/unit	# people	# hours
Water tank	$/unit	-	-
Mill	$/unit	# people	# hours
Administration building	$/unit	# people	# hours
Market	$/unit	# people	# hours
Hospital	$/unit	# people	# hours
Health post	$/unit	# people	# hours
Main school	$/unit	# people	# hours
Main road (paved)	$/m’	-	-
Community road (for vehicles, unpaved)	$/m’	-	-
Community bridge (for vehicles, unpaved)	$/m’	-	-
Power line (including lighting poles)	$/m’	-	-
Reservoir (including pumps)	$/unit	-	-
Irrigation channel	$/m’	-	-
Communication infrastructure	$/unit	-	-
Outdoor water pipe	$/m’	-	-
Orchard	$/ha	-	-
Corn and bean fields	$/ha	-	-
Pastures, grasslands	$/ha	-	-
Fruit trees	$/ha	-	-

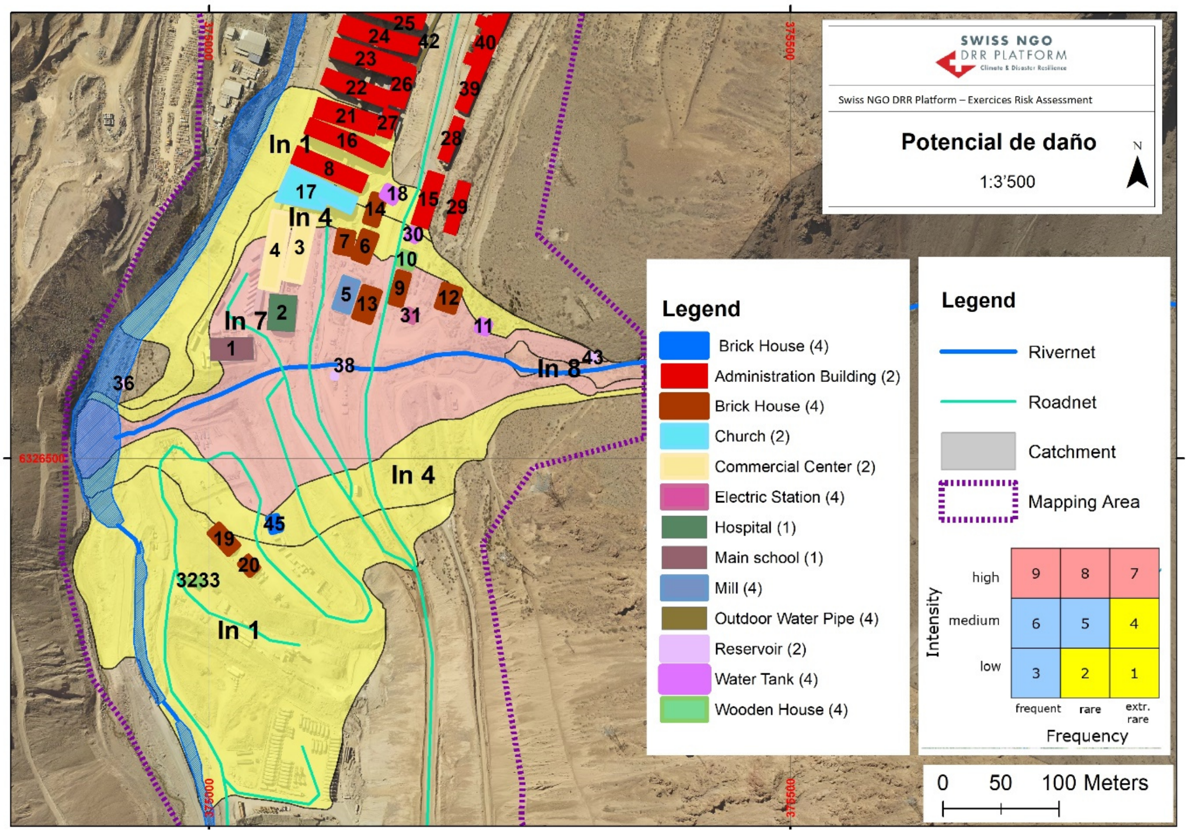

Illustration 6: Part of a hazard map with classification and sequential numbering of the damage potential.

Step 3: Determining the need for protection

The hazard tolerance threshold for all types of damage potential is defined in consultation with the authorities. The tolerance threshold describes the maximum tolerable hazard level for a given type of damage potential. As a general rule, the tolerance threshold for buildings is stricter than that for agricultural land. For buildings, the protection requirements for sensitive objects, such as a hospital or a school building, are stricter than for residential buildings. By comparing the tolerance threshold with the existing hazard, it becomes clear whether and where a protection deficit (protection need) exists. If several objects with a protection deficit are found, a risk and cost-benefit analysis is recommended to check the cost-effectiveness of possible measures.

Table 2: Example of a matrix with the definition of hazard tolerance thresholds for different types of objects. These must be defined among decision-makers. If possible, the same protection objectives should always be applied within the same municipality.

	1	2	4	5	3	6	7	8	9
Farmland	admitted	admitted	admitted	admitted	admitted	admitted	admitted	Protection deficit	Protection deficit
Individual buildings local infrastructure facilities	admitted	admitted	admitted	admitted	admitted	Protection deficit	Protection deficit	Protection deficit	Protection deficit
Infrastructure facilities of public interest (roadways)	admitted	admitted	admitted	admitted	admitted	Protection deficit	Protection deficit	Protection deficit	Protection deficit
Infrastructure facilities of public interest (buildings)	admitted	admitted	admitted	Protection deficit	Protection deficit	Protection deficit	Protection deficit	Protection deficit	Protection deficit
Dense settlement area	admitted	admitted	Protection deficit	Protection deficit	Protection deficit	Protection deficit	Protection deficit	Protection deficit	Protection deficit

admitted

Protection deficit

Step 4: Risk calculation for the current situation

MiResiliencia Web-GIS application

The attached video instructs the user on how to use the MiResiliencia tool. The user defines the risk assessment area as the first step. Within this area, the hazard map prepared in the field and in the office is digitized. The objects to be analyzed (damage potential) are digitized within the tool. All objects where income is generated (cultivation areas, factories, offices, ...) are assigned the capacities of the people inside them.

As a further step, the planned measure(s) to reduce the threatened area or degree is digitized.

Alternative Risk Excel-Tool

Objects that demonstrate a protection deficit (tolerance threshold exceeded) will be marked on the hazard map. Each of these registered objects is considered in the calculation tool in the Annex (1 object per line). They will be provided with the following risk information:

- Hazard level to current state
- Number of floors per building or number of hectares per agricultural land
- For commercial areas or buildings: average daily production per object or per hectare
- Social capacity (see "Social_Capacity" folder in the calculation tool)

The tool then calculates the risks of direct and indirect damages for all registered objects.

Step 5: Planning mitigation measures

Experts should be consulted on the design of mitigation measures. The design is not part of this guide[2]. In cases of planned structural measures, their effect should be shown on a modified hazard map (hazard map with planned measures). In cases of non-structural measures, the capacity factor changes, but not the hazard level. Within the calculation tool, the costs of the measure and its lifetime must be recorded.

Illustration 7: Riverbank protection wall to protect buildings from floods. Birendranagar, Nepal.

Step 6: Risk calculation for the projected condition with measures

In the calculation tool, the hazard level is assigned for all registered objects, taking the measures into account. For non-structural measures, the increased planned capacity factor is entered.

Step 7: Examination of the cost-effectiveness of measures

The tool in Annex calculates the cost-efficiency of the planned mitigation measure with a cost-benefit factor, comparing the risks without and with the measure, and taking into account the costs of the measure. In mathematical terms, measures with a cost-benefit factor > 1 are cost-efficient. However, due to the often limited financial possibilities, the Swiss Red Cross recommends setting the cost-efficiency limit at factor 5.

[2] www.wocat.org could build a reference for mitigation measure planning.

Cost-benefit factor < 1:	red	Measure implementation not recommended
Cost-benefit factor 1 -5:	orange	Low cost-efficiency of measure
Cost-benefit factor > 5:	green	Measure implementation recommended

If the planned measure is not cost-efficient, an alternative measure should be pursued or the request for funding rejected.