



Landslide Consequences and Post Crisis Management Along the Coastal Slopes of Normandy, France

Lissak Candide, Maquaire Olivier, Anne Puissant, and Jean-Philippe Malet

Abstract

The coastal slopes of the Pays d’Auge plateau (Calvados, Normandy, France) are regularly affected by landslides mainly triggered by rainfall. The study area between Trouville and Honfleur has been subject to slow continuous displacements ($5\text{--}10\text{ cm}\cdot\text{year}^{-1}$) for several centuries, punctually disturbed by episodes of acceleration with metric displacements. The landslides are located along a very touristic coastal area where increasing land pressure is evident.

Because of the potential for crisis and the seasonal landslide activity, direct or indirect, immediate and delayed impact have been identified. Since the first reactivation of the largest landslide in 1982, direct damages to infrastructures (roads, buildings...) and indirect damages to the economy have been observed.

The objective of this work is to present the risk assessment carried along the Normandy coasts through the: (1) evaluation of the long-term landslide consequences, (2) identification and value of the actual elements at risk including potential consequences and (3) analysis of the policy responses during the past 30 years.

Keywords

Slow moving landslide • Risk assessment • Potential consequences • Element at risk • Risk management • Resilience

Morphostructural Specificities an Occurrence of Coastal Landslides in Normandy

The investigation of landslide risk analysis first requires the conceptualization of the hazard (Alexander 2005). On the edges of the Pays d’Auge plateau, between Trouville-sur-mer

and Honfleur (Fig. 1), several slope instabilities are notable. We focus this paper on the ‘Cirque des Graves’ landslide, the most important rotational translational landslide occurring on this coast. Mass movements have occurred quite low on convexo-concave slopes but are very heterogeneous in their stratigraphy and their morphology. Previous studies highlighted the role of hydro-climatic conditions in the landslide triggering and the importance of the nested chalk panel derived from the plateau (major component of the landslide) as well as the superficial deposits in the landslide dynamics (Flageollet and Helluin 1987; Maquaire 1990).

Along 7 km of coastline, five active landslides (Varnes 1978) are visible of which two (*Cirque des Graves*, *Fosses du Macre*) are characterized by a seasonal velocity pattern ($5\text{--}10\text{ cm}\cdot\text{year}^{-1}$) sometimes affected by acceleration episodes inducing several meters of displacement, large cracks and high scarp emergence. Since the first instability of these

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Fig. 1 Location of the two biggest landslides between Trouville-sur-mer and Honfleur

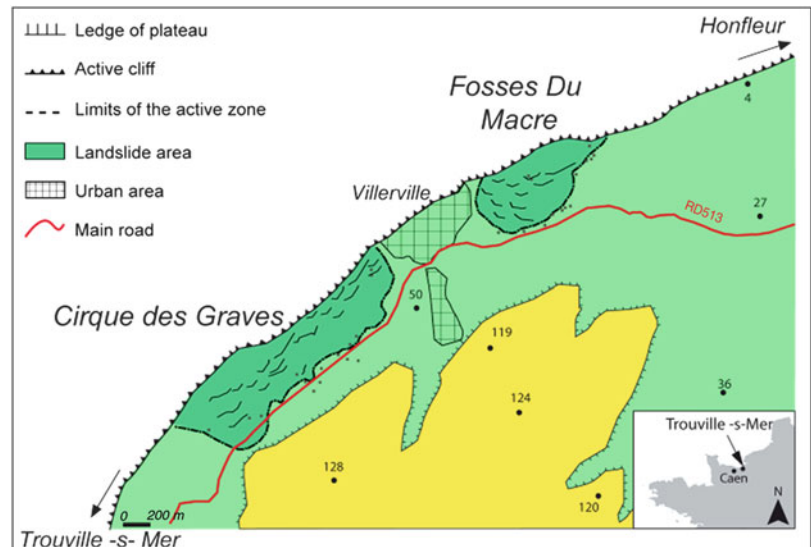
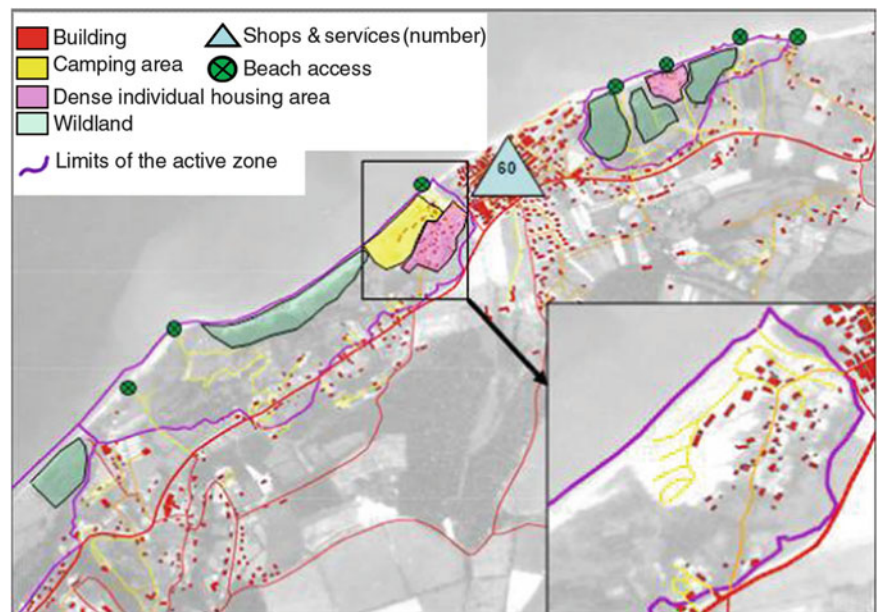


Fig. 2 Before the crisis situation of the *Cirque des Graves* and the *Fosses du Macre* landslide site development



two landslides (not precisely dated during Holocene period) several accelerations occurred in the last two centuries (Ballais et al. 1984) but all the events remain undated until the end of nineteenth century (1880). The multiple accelerations, particularly the recent reactivations (January 1982, February 1988, January 1995 and March 2001), occurred during the rainy season and have generated successive scarps that are several meters high (2–5 m) with toppled blocks and significant collapses (5 m fell down in 1982 at the “Cirque des Graves”) (Flageollet and Helluin 1987; Maquaire 1994).

Local Scale Consequences and Management Analysis

Pre-Crisis Situation

Because many landslides have been triggered in the past 30 years and in order to define the overall landslide impact since the first occurrence, it is necessary to identify the state of the area (economic system with activities, urban extension...) in existence prior to the impact in order to

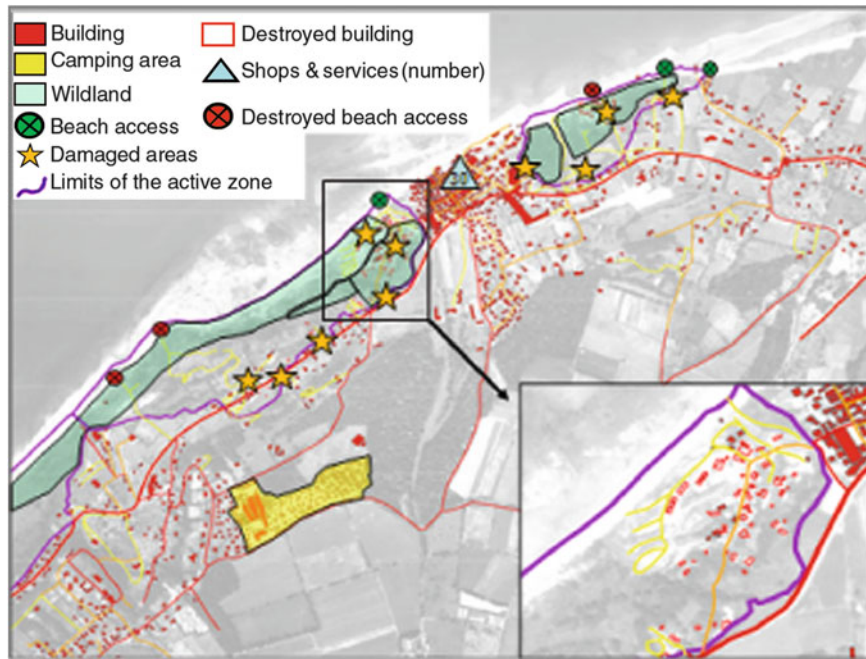


Fig. 3 Situation of the *Cirque des Graves* and the *Fosses du Macre* landslides after four reactivations and location of the landslides impacts



Fig. 4 East part of the main scarp of the *Cirque des Graves* landslide in 1982. On the toe of the landslide, several houses and tourist accommodation, now completely destroyed

define the historical damages. Historical documents, archives, pictures, cadastral maps and aerial photographs, etc. indicate the location and state of buildings and the land-use before the first acceleration took place at the end of the nineteenth century. To complete the information, interviews with local authorities or residents was undertaken regarding the spatial and the economical dynamics of the area (Fig. 2) before the events. Research indicates an attractive area for residents and tourists with access to the sandy beach, tourist infrastructures on the active zones, and shops and services (Fig. 2).

Direct and Immediate Consequences

At the time of the failure, networks such as lifelines and roads would have been cut at several points by the landslide. The most affected road was the departmental road, the principal route (in red) connecting several towns and cities. During the various events, the road has been cut at four points causing its closure for several days (Fig. 3) and thus disrupting traffic.

For the *Cirque des Graves* landslide, most of the damage occurred during the 1982 reactivation. Before the catastrophic event, despite the slope morphology which suggested the slope instability (scarps, counter slopes...), the most active part of the landslide was consequently developed by contractors. This first big reactivation resulted in the destruction or the damage of about 80 buildings (Fig. 4, Table 1). We can distinguish the affected buildings by their height with the number of levels and their construction material (Table 1). Among all these losses and fatalities, very important tourist infrastructures were destroyed at the toe of *Cirque des Graves* landslide. A famous camping area whose capacity was about 2000 tourists per month in the summer season was completely destroyed. Because of its economic importance to the municipality of Villerville, the camp site was relocated upstream, on a stable part of the slope, on municipality parcels, to minimize the socio-economical impact of the landslide.

Table 1 Physical injuries induced by accelerations crisis

Building			
Floor NB	Building material	Function	Number
R + 2 or 3	Traditional masonry	Residential	8
R + 1	Traditional masonry	Residential	9
R + 0	Traditional masonry	Residential	11
R + 0	Traditional masonry	Leisure	5
R + 0	Traditional masonry	Annex	6
R + 0	Wood	Residential	48
R + 0	Wood	Leisure	2
R + 0	Wood	Annex	14
Destroyed			103
R + 2 or 3	Traditional masonry		19
Damaged			19
TOTAL			122

On the *Fosses du Macre* landslide the first important reactivation of 1988 caused the destruction of several buildings (Table 1) located at the landslide toe. But during the 2001 event, several multistage and typical Norman homes were damaged because of the main scarp regression.

Indirect Consequences

Beyond the physical and direct impact of the landslides on the infrastructure, we focused our study on the indirect and long-term consequences of the hazard on the economic dynamics and the functioning of the affected area.

At first, analysis focused on the post-crisis consequences, a few years ($< 10\text{year}^{-1}$) after the first landslide reactivation. The relocation of the tourism facilities and the building destruction had consequences: (1) the abandonment of land by owners with the conversion of gardens into wasteland (shrub), (2) the closure of access to the beach, (3) the closure of many shops and services in the town, (4) a decrease of tourism for the town, (5) the relocation of tourism infrastructure upstream, and (6) the departure of many residents.

The Villerville village with the *Cirque des Graves* landslide was the most affected area of the 1980 events, with numerous socio-economical consequences on the territorial dynamics. Concerning the population, although the trend of the department is a negative net migration of coastal towns, departures of residents in the municipality of Villerville were more important between 1982 and 1990 than compared to other villages (Fig. 5).

Next we focused on the long-term consequences, several decades after the 1982 reactivation.

The first administrative measure was to establish a decree on the plots located on the active zone. Consequently the zoning of lands in the red zone of the PPR (areas with specific restriction to planning according to the hazard) (Fig. 6) induced an important financial depreciation of the plots and the buildings regulations, in and near the active zone.

Following this decree, a conversion of the land-use in the east part of active zone was noticed (where the largest structural damages were reported) with the development of open spaces, recreational areas with leisure facilities mixed with ecological conservation zones as Protected Natural Areas (ponds. . .).

For the Villerville town, after the closure of several stores and shops (about 60 shops and businesses in 1982 against 30 in 2009), the economic center (shops and basic services) was moved to the top part of the village, on both sides of the departmental road (Fig. 7).

Policies Management

Risk Prevention

Landslides, as one of the major natural hazards, account each year for enormous property damage in terms of both direct and indirect costs. Planning control is one of the effective and economical ways to reduce landslide losses (Dai et al. 2002). In Europe, national legislation and guidance for the most part provide a strategic framework for land-use and development (Mc Innes 2005). In France, in order to reduce the number of elements at risk and for preventing natural hazards, the adjustment policies for risk management are based on two mapping tools conventionally used as support for planning control. On the one hand, the hazard maps at 1/5,000 or 1/10,000 scales to integrate the Local Development Plan (Plan Local d'Urbanisme – PLU). This document is necessary for municipalities to take into account natural hazards in their planning policy. Generally, risk assessments are considered by delineation of affected zones, then by their restriction regarding their use (Hollenstein 2005). On the other hand, the Prevention Plan Natural Hazards (Plan de Prévention des Risques – PPR) established since 1995 to simplify the display of the risk and substitute several existing documents as PER (Risk Exposure Plans) since 1982, or ZERMOS maps for instabilities (areas at risk of ground motion and basement) in 1975. By the various documents, new developments can be prohibited, restricted or regulated in areas prone to landslides. Nevertheless sometimes these documents are not sufficient to protect civilians from disaster and damages still occur with direct and indirect losses. Consequently we wonder about the stakeholders' response to adapt to the disaster.

Post Crisis Intervention

In response to the various events, the management strategy has been progressive, involving multiscale stakeholders to acquire a steady state of the socio-economic planning. Since the 1982 event, interventions in response to disaster were

Fig. 5 Actual situation of the study area development

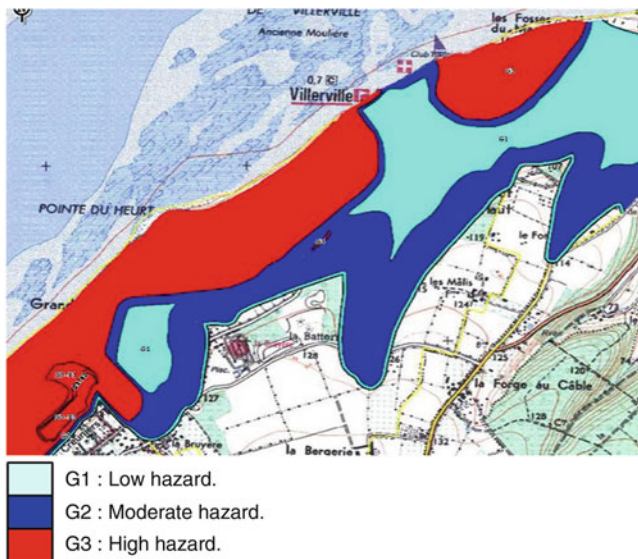
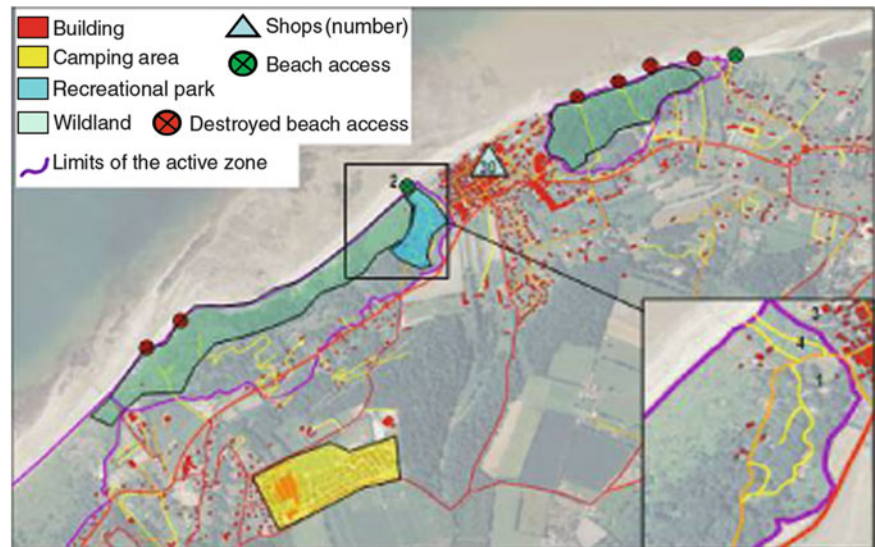


Fig. 6 Actual PPR in progress

progressive (Fig. 8): (1) with, at first, a non-integrated management by local stakeholders and departmental planners and recently (2) an integrated land management with a collaborative decision making between actors.

The first step of the post-crisis management consisted in (Fig. 8):

- Immediate public policy and decrees institution with dangerous building ordinance, legal ruling on almost all properties of the active zone of the *Cirque des Graves*, and the relocation of the camping on the plateau,
- Acquisition of affected plots by the government and the municipality, land-use restriction
- Latency period between hazard occurrence, decision-making strategies to alter, define, and reshape economical



Fig. 7 Illustration of the actual park where leisure facilities and tourism infrastructures are next to ecological protection areas

activities in particular ways – Reflection on the site conversion possibilities

- Destruction of the damaged houses and clean up abandoned plots to rehabilitate the unstable area.

The last step of the governance consists in the rehabilitation of the area by decision-makers. The final step defines an ability to restore and improve the area after a crisis. The various stakeholders (mayor, department, region . . .) are involved in different scales on the territorial dynamics and in the planning and building control (Fig. 8) through: (1) The restriction of the urban development whereas the land pressure is increasing, (2) the rehabilitation and conversion of the land-use to inflate the local economy. This readjustment is based on tourism activities as a principal economical agent, with the development of tourist facilities (camp facilities relocated to the plateau on a municipality parcel), grant of trades, and the rehabilitation of abandoned land in open space, parks, woodland and recreational area.

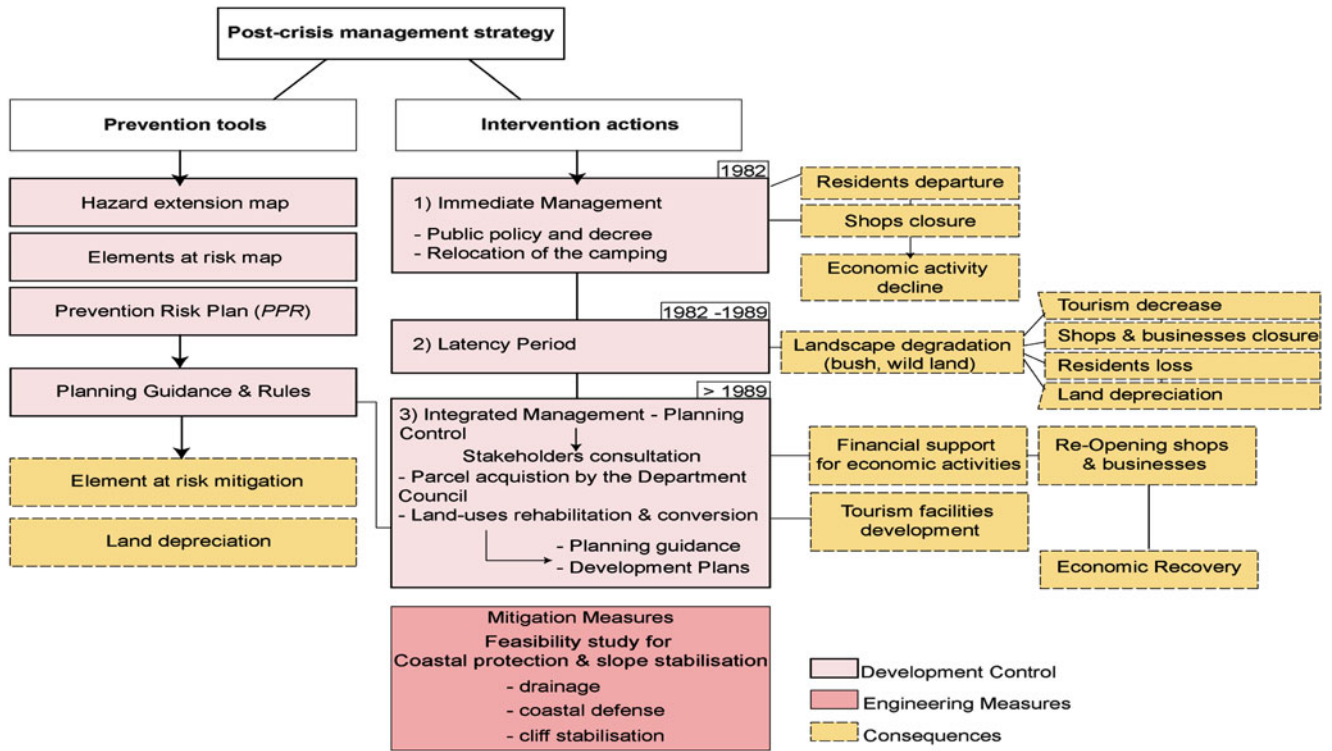


Fig. 8 Villerville municipality: ‘Cirque des Graves Landslide Management Strategy’

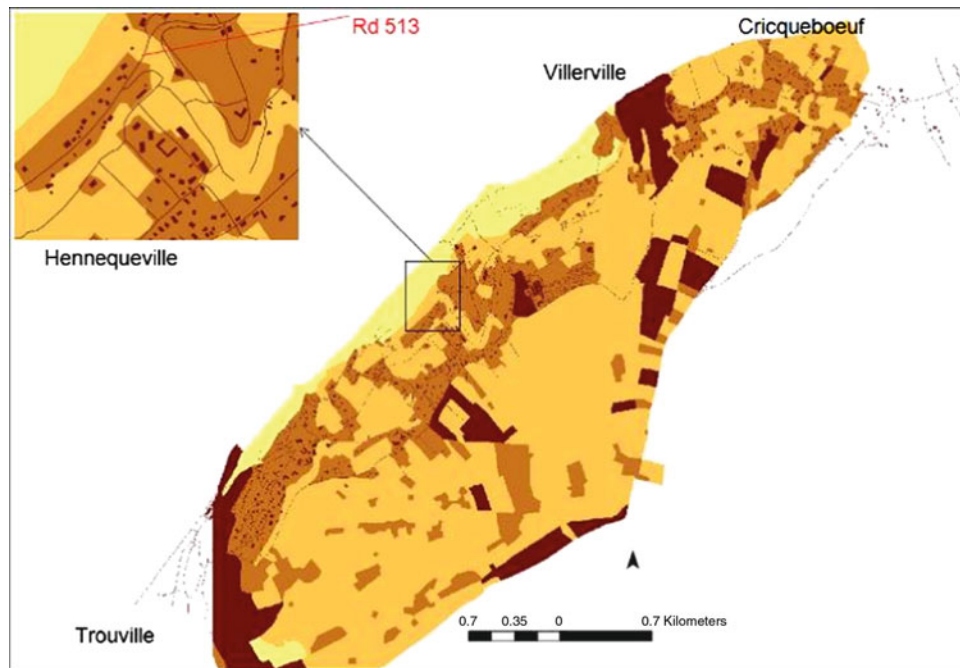


Fig. 9 Element at risk identified around the fourth major landslides between Trouville-s-mer and Honfleur. Class (1) Very low potential consequences (clear color), Class (4) High potential consequences (dark color)

In the absence of sufficient funding, no specific measures have yet been adopted to reduce the hazard. Only, some owners have installed a surficial drainage system. At the *Fosses du Macre*, a sea wall has been constructed in

the middle of 1980s, but landslides still occurred three times (1988, 1995 and 2001) so that it was necessary to evaluate the actual potential consequences in case of landslide reactivation.

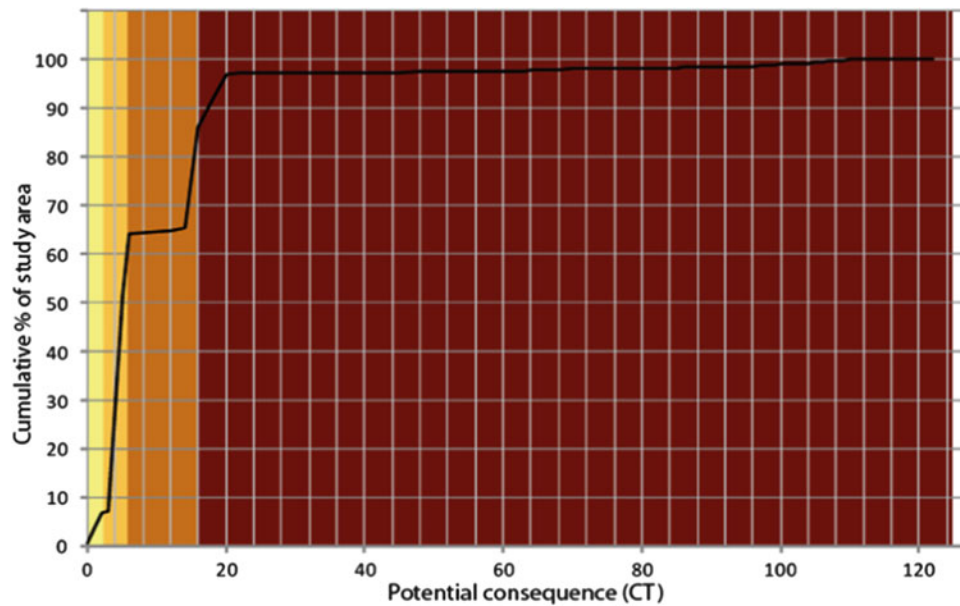


Fig. 10 Classification of element at risk (four classes) and percentage of affected area between Trouville-s-mer and Honfleur

Regional Scale Potential Consequence

Exposed Element at Risk: Identification and Value

Thus, to define the global impact of the landslides on the territory system we focused our attention on the current regional elements at risk and on the potential consequences and losses in case of landslide extension. The consequences are linked to elements at risk and their vulnerability (Glade 2005). Several approaches and methodologies have been developed to quantitatively evaluate the potential consequences of the hazard from the identification of exposed elements. The elements at risk, considered as issues, are classified and assigned a value (Leone 2008; Abella and Westen 2007; Castellanos et al. 2007; Puissant et al. 2006; Glade 2005; Bonnard 2004) according to their potential consequence typology and importance.

At a regional scale, elements at risk are identified beyond the geometric boundaries of the active zone, in case of the extension of the landslide. Using an index to value elements at risk according to their vulnerability and potential consequence is a widely used method because of difficulties to obtain real economic data (Leone et al. 1996). Using GIS technology, the potential consequences of elements are firstly based on the knowledge of historical landslides losses and fatalities.

The elements at risk are associated with a coefficient index expressing the relative value of the object (Amatruda 2004; Maquaire et al. 2004) and classified in different categories according to the nature of the vulnerability

(Puissant et al. 2006): Physical injury, structural and functional injury and socio-economic effects (Figs. 9 and 10). This study is based on a preexisting semi-quantitative method (Puissant 2006). The aim of this new application is to adapt the semi-empirical model developed into mountainous environment (French south Alps) to a coastal environment, in order to provide comparable results based on the same methodology. For the elements at risk characterization, some parameters have been adapted to the coastal location as tourism infrastructures and importance of road networks.

Exposed Element at Risk: Computation

Once all indexes are defined for each element at risk, the vulnerability is expressed according to the potential landslide consequences. These potential consequences (physical, structural, functional and socio-economical) as direct and indirect effects of the landslide are combined (Fig. 9) to highlight the importance of networks and the building function on the socio-economic dynamic of the area.

Conclusion

Landslides can result in many casualties and significant economic losses (Dai et al. 2002) but fortunately, large permanent slow moving landslides are not a risk to life (Hollenstein 2005). A global risk assessment is usually performed through hazard analysis and then by a vulnerability assessment. But if the disaster has already occurred, inducing catastrophic damages; losses have to be defined for preventing damages in case of landslide

reactivation. In our case study, to evaluate the total consequences of a mass-movement on the society, first, we compiled historical damage assessment and actual elements at risk analysis. Because, risk managers and authorities need sufficient knowledge about past and potential impacts of the hazard and possible consequences of the different decision options to control the risks (Renn and Schweizer 2009). Secondly, our study focused on the post-crisis management developed by authorities characterized initially by a ‘day by day’ management with a few consultations between actors, and without any real global strategy. But gradually, an integrated risk management with collaboration of the different scale stakeholders allowed us to develop new economic activities in the areas affected by landslides and to reduce the potential consequences.

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