How do humans interact with their environment in residential areas prone to landsliding - a case-study from the Flemish Ardennes -

Miet Van Den Eeckhaut (1,2), Jean Poesen (1), Marijn Van Gils (1), Anton Van Rompaey (1), Liesbeth Vandekerckhove (3)

(1) Physical and Regional Geography Research Group, K.U.Leuven, Belgium,
(2) Research Foundation - Flanders, Belgium,
(3) Environment, Nature and Energy Department, Flemish Government, Belgium
1. Problem statement and objectives

The interaction between humans and the environment is a central theme in geography. In most landslide studies, attention is mainly paid to the influence of natural factors on the occurrence of landslides. Humans are mainly regarded as subjects that are vulnerable to landslides, and not as actors influencing slope stability (Panizza 1999).

Recent studies focusing on the effect of human-induced land use changes on slope stability (e.g. Vanacker et al. 2003; Petley et al. 2007; Meusburger and Alewell 2008), however, have shown that in populated regions, the impact of humans on the environment contributes significantly to the initiation and reactivation of landslides.

Therefore, the objective of this study is: **to analyse the human - environment interactions and their influence on landsliding in the Flemish Ardennes.**
1. Problem statement and objectives

Human-environment interactions and their influence on landslides in the Flemish Ardennes

- Which environmental characteristics control the location and triggering of LS?
  - Controlling factors
    - Slope gradient (> 10 m/m)
    - Aspect (S to NW facing slopes)
    - Lithology (smectite clay)
  - Triggering factors
    - Climate
      - Old, deep-seated LS: Periglacial conditions
      - Recent, shallow LS: Antecedent rainfall (>1000 mm and >1000 mm in month and year preceding slope failure)
    - Seismicity
      - Old, deep-seated LS: Earthquake
  - How does LS susceptibility affect human activities through time?
    - Impact of LS on humans
      - Land use in LS affected sites (farm and pasture)
      - Settlements in LS affected sites (increase in second half of 19th century)
      - Structural damage to buildings, roads and other infrastructure

- How do humans affect landslides?
  - Impact of humans: controlling and triggering factors
    - Decrease of soil shear strength / Increase of shear stress
      - Overloading of upper part of the slope
      - Removal of lateral support on foedslope
      - Lateral pressure
      - Increase in pore water pressure

- What are the implications for land management?
  - Prevention and mitigation measures for policymakers and planners
    - Applying specific land use regulations to the susceptibility zones on the classified LS susceptibility map
    - Landslide test (Dutch: “grondverschuivingstoets”)
    - Impact of climate change (increase of slope failures in winter)
2. Study area: the Flemish Ardennes

- **Climate**: maritime temperate humid climate with mild winters;
- **Topography**: hilly region, altitudes from 10 to 150 m a.s.l.; 99.5% of the area has a slope gradient < 20%; valley-asymmetry: S to NW oriented slopes are steeper;
- **Tertiary lithology**: alternation of sands and less permeable smectite-rich clays;
- **Hydrology**: many springs, high drainage density.
Honderden huizen riskeren verzakking

In gebieden met een hoog risico op grondverschuivingen moet een ‘grondverschuivings-toets’ worden uitgevoerd alvorens een bouwvergunning af te leveren. Op dit moment riskeren honderden huizen in de Vlaamse Ardennen verzakking.


Uit dat onderzoek blijkt dat honderden eigenaars een groot risico lopen dat hun huis verzakt en/of barst. Zo'n 80 km², waarvan 6 km² in woon- of woonuitbreidingsgebied, is matig tot zeer gevoelig voor grondverschuivingen. De zones liggen onder meer in Roeselare, Maarkedal, Kluizenberg, Hoegaheen, Zottegem en Zonhoven.

Een grondverzakking in de Vlaamse Ardennen. (Foto: G. Van de Velde)
3. Which environmental characteristics control the location of landslides?

A. Landslide inventory map

Analysis of LIDAR-derived maps allows a clear and detailed overview of large landslides, even when they are located under forest.
Analysis of LIDAR-derived maps allows clear and detailed overview of large landslides, even when located under forest ...the Muziekbos landslide as an example
3. Which environmental characteristics control the location of landslides?

A. Landslide inventory map

=> 163 large (>1–40 ha), deep-seated (est. >3 m), old (> 30 yrs - Early Holocene)

The inventory map shows the location of more than 200 landslides (1% of the study area)

=> 49 small (<1 ha), shallow (est. <3 m), recent (15 yrs),

Van Den Eeckhaut et al. (2007)
Using a multivariate statistical model, i.e. rare events logistic regression (RELR) (Van Den Eeckhaut et al., 2006) the probability of landslide occurrence, \( p_i = P(Y=1) \), was estimated as:

\[
\log\left(\frac{p_i}{1-p_i}\right) = -13.42 + (0.39\times \text{hillslope gradient})
+ (2.41\times \text{GeMe}) + (2.33\times \text{GeVl}) + (1.49\times \text{Tt}) + (1.38\times \text{KoAa})
+ (2.52\times \text{NW}) + (2.95\times \text{W}) + (2.04\times \text{SW}) + (2.40\times \text{S}) + (1.65\times \text{SE})
\]

-> existing and future landslides are expected to be located on rather steep slope gradients with S to NW orientations, and lithologies rich in swelling clays (i.e. KoAa, GeMe, Tt).

Evaluation and validation of this model showed that the model had a high quality (i.e. indicated most existing LS sites as highly susceptible, without classifying large percentages of the study area as highly susceptible).

-> a LS susceptibility map can be created.

Van Den Eeckhaut et al., 2006; 2007; http://www.lne.be/themas/bodem/grondverschuivingen/grondverschuivingen
3. Which environmental characteristics control the location of landslides?

B. Landslide susceptibility map

Overlay with old, deep-seated landslides

84% of the areas affected by an old landslide are correctly classified as zones with very high to moderate susceptibility (11% of the study area).
Hypotheses:

At present people are living, working, driving on or close to landslide sites. In historical and prehistorical times, however, people were more familiar with local environmental constraints (such as the presence of landslides).

Hence, few old settlements are expected to be found on landslides (study 1) and over time human occupancy on landslide susceptible sites is indeed increasing (study 2).

**Study 1**: Confrontation of landslide inventory and susceptibility map with location of archaeological sites in the study area

Archaeological data (Mesolithicum – 1800 AD) was taken from the “Central Archaeological Inventory”
(http://cai.erfgoed.net/; Meylemans et al., 2004)
“Central Archaeological Inventory”

An electronic relational database designed for heritage management including for the whole of Flanders more than 22,000 archeological locations (Mesolithicum – 1800 AD)
“Central Archaeological Inventory”
4. How does landslide susceptibility affect human activities?

Influence of landslides on location of settlements and evolution through time: Study 1
4. How does landslide susceptibility affect human activities?

Influence of landslides on location of settlements and evolution through time: **Study 1**
4. How does landslide susceptibility affect human activities?

Influence of landslides on location of settlements and evolution through time: Study 1

There is indeed a very limited presence of prehistoric settlements or stray finds on landslide-affected or landslide susceptible hillslopes.

However, care should be taken when drawing final conclusions because the absence of historical settlements on unstable hillslopes might also reflect:

(i) that archaeological findings have been removed or covered with debris after landsliding or water erosion, or

(ii) that past archaeological studies have focused on the cropped loess plateaus and not on the landslide susceptible hillslopes that are often located under forest.
4. How does landslide susceptibility affect human activities?

Influence of landslides on location of settlements and evolution through time: Study 1

Although further detailed archaeological surveys on hillslopes are required to draw final conclusions, our results reinforce our hypothesis, i.e. that prehistoric and historic people were indeed more familiar with local natural hazards, such as landslides and therefore avoided these landslide susceptible areas.
Study 2: Evolution of recent human activity (i.e. buildings) on landslides in Ronse and Maarkedal

Influence of landslides on location of settlements and evolution through time: Study 2

Possible errors are mainly related to:

1. The planimetric accuracy of the original historical maps (e.g. degree of rotation, shrinkage and stretching) or resulting from scanning and georeferencing of the maps;
2. The digitizing of the nearly contiguous buildings.

4. How does landslide susceptibility affect human activities?

Influence of landslides on location of settlements and evolution through time: Study 2
4. How does landslide susceptibility affect human activities?

Influence of landslides on location of settlements and evolution through time: **Study 2**

E.g. Waardebroeken landslide (Maarkedal)

- Increase from 3 to 7 buildings
4. How does landslide susceptibility affect human activities?

E.g. Muziekberg landslide (Ronse) - the largest landslide (42 ha)

Despite the facts that (i) typical morphological characteristics; (ii) a more recent landslide of 1926; and (iii) the river displacement downslope of the landslide foot by landslide debris are clearly visible in the field and on LIDAR-derived maps, many landowners were not aware of the presence of this landslide when constructing their house on this site.

The vicinity of the city of Ronse, the scenic view on the Rone valley and the large size of the landslide (making it more difficult to identify the landslide), explain the increase in buildings.
4. How does landslide susceptibility affect human activities?

Influence of landslides on location of settlements and evolution through time: Study 2

(A) Between 1777 and 2002, the number of landslides on which buildings were constructed increased from 14 (or 22.0%) to 16 (or 27.1%) out of 59 mapped landslides.

(B) The number of houses within these landslides, however, increased from 109 buildings around 1777 to 221 around 2002.

New buildings on landslide-affected sites were mainly constructed during the last five decades investigated in this study (i.e. 150 buildings in 1955 and 221 buildings in 2002).
5. How do humans affect landslides?

Causal factors of active landslides (n=43; 20%) in the 710 km² study area

Generally both natural and anthropogenic factors contribute to the local instability.

Natural triggering factors are always high antecedent rainfall depths (i.e. > 100 mm and > 1000 mm in the month and year preceding the landslide reactivation or initiation; Van Den Eeckhaut 2006).

Human interventions are: overloading of the depletion area (e.g. construction of buildings and other infrastructure), removal of hillslope material (i.e. lateral support; e.g. construction works), poor drainage (insufficient sewerage systems), obstruction of springs and increased surface runoff from the upslope drainage area towards the main scarp.

Active landslides (n=43):
- are reported to be active;
- show traces of activity.
5. How do humans affect landslides?

(e.g. Guzzetti et al., 2002; Malamud et al., 2004)

- Mountain areas where historical and recent LS are mainly triggered by natural factors and large-scale human interventions;
- Positive power-law for small LS, negative power-law with $\beta \approx 2.4$ for larger LS, and rollover in transition zone.
5. How do humans affect landslides?

- Populated hilly regions where local human interventions are causing shallow LS;
- Negative power-law with $\beta << 2.4$ for recent shallow LS, and distribution similar to A for historical and incomplete inventories of deep-seated LS.
Landslide studies in residential areas not only require a detailed analysis of the natural factors controlling and triggering landslides. Also detailed information on the impact of human activities on and close to inherently unstable hillslopes is needed.

In the Flemish Ardennes landsliding is an important degradation process as the regional inventory map contains 210 landslides.

**IMPACT OF LANDSLIDES ON HUMAN ACTIVITIES**

-> Application of a logistic regression model showed that hillslope sections with S to NW orientation, with a slope $> 0.10$ m.m$^{-1}$ and with clay lithology at relatively shallow depth are most susceptible to landsliding.

-> Confrontation of the susceptibility map with archaeological locations and with buildings indicated on historical maps (1777-2002) shows that especially during the last 50 years of the 20th century the number of houses within landslides increased. Hence, this case-study indicates that despite progress in understanding of geomorphic hazards made over the last decades, humans now seem to pay less attention to the physical hazards in their environment compared to the previous generations.
6. Conclusions

IMPACT OF HUMANS ON LANDSLIDES
-> Investigation of causal factors reported to have initiated recent landslides reveals that humans can significantly reduce slope stability, and initiate landslides.

-> Also the frequency distribution of landslide areas suggests a shift in importance of landslide causal factors in the Flemish Ardennes: i.e. from mainly natural causes towards more anthropogenic causes.

The observed increasing trend of human influence on landslide susceptible sites, and its impact on slope stability is representative for residential areas in many hilly and mountainous regions throughout the world.
The presented landslide susceptibility map provide a tool for landslide risk reduction in these areas.
Improve study 2: Evolution of recent human activity (i.e. buildings) on landslides in Ronse and Maarkedal

- Until now only the evolution of buildings within landslides was studied.

- However, final conclusions can only be drawn when the observed increase of buildings within landslides is compared with the overall evolution of buildings throughout the two municipalities.

- Problems:
  (1) buildings are often contiguous in densely populated zones;
  (2) evolution of buildings within landslides and outside landslides depends on many other factors (e.g. social and industrial history of the municipalities, availability of buildings grounds).
  (3) …

- Currently, we are investigating how to overcome these problems.

7. Future research


Van Den Eeckhaut, et al., in press. Evidence for repeated re-activation of old landslides under forest. ESPL.

Van Den Eeckhaut et al., submitted. Combined landslide inventory and susceptibility assessment based on different mapping units: an example from the Flemish Ardennes, Belgium. NHESS.

Van Den Eeckhaut et al., submitted. Human-environment interactions in residential areas susceptible to landsliding: the Flemish Ardennes case-study. Area.