

State-of-the-Art of Landslide Site Monitoring in Europe: Preliminary Results of the SafeLand Questionnaire

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Inventory, complex investigation and monitoring of high-risk slope failures are essential tasks for any effective early warning and risk management worldwide. Different approaches are being applied for different sites regarding the affected mass parameters, behaviour, activity state and national tradition as well. However, a summarizing study to compare approaches throughout Europe is still missing. Therefore we prepared a **Questionnaire on National State of Landslide Site Investigation and Monitoring**, which was disseminated among European institutes and representatives within the frame of the SafeLand project.

The principal goals and expected output of the questionnaire study were:

- Assessing **general state** of the slope-instability investigation and monitoring in different (all) European countries
- Assessing **effectiveness / reliability** of each method for slope-instability investigation and monitoring
- **Applicability** of the monitoring techniques **for early warning**.

This was done through tick-answering and was an input for the statistical assessment.

The **general information on monitored mass movement** (slope failure typology, activity state and recent movement rates) was expressed relative to the total number of phenomena. The **investigation methods** (testing, mapping, ground-based geophysical surveys and remote-sensing data) were assessed by relative occurrence (%) per total number of case sites and their relative reliability (%), evaluated by authors of the answers. **Methods of landslide monitoring** (monitoring of displacement and deformation, hydrometeorological factors, and geophysical factors) were assessed by their relative occurrence (%) per total number of case sites. Another parameter, the index of early warning potential of each method, was given by positive answers on the possibility to use the method for EW relative to occurrence of the method, divided by total number of sites. General outlines and graphical outputs of the study are presented in Table 1 and Figures 2–11.

The most abundant slope failures that have been monitored were active translational and rotational slides with recent movement rates less than 10 mm/month. The most frequently applied **investigation methods** were geological, geomorphic and engineering-geological mapping and core drilling, testing of strength properties / deformability and clay mineralogy, studying of aerial photographs, LiDAR airborne laser scans (ALS), radar interferometry, resistivity measurements and refraction seismic.

Aerial photographs, satellite optical very high resolution (VHR) imagery, LiDAR ALS, radar interferometry and measuring of resistivity, reflection and refraction seismic, time-domain electromagnetic, passive acoustic emissions, geophysical logging were **the most reliable investigation methods**.

Monitoring of movement and deformation was most frequently done by repeated orthophotos, radar interferometry, differential LiDAR ALS, webcam, dGPS, total station, inclinometer (classical) and wire extensometers. Most frequently **monitored hydro-meteorological factors** were precipitation amount, pore-water pressure and air temperature; the most frequently monitored **geophysical parameters** were passive seismic/acoustic emissions, electromagnetic emissions and direct current resistivity. However, distinct differences in application of individual methods, especially in the case of remote-sensing data and new technologies, were observed between the countries of the former eastern and western block. Also, different slope failures need different investigation and monitoring approaches. The study will be finalized in the near future, after evaluating more answers from other countries.

QUESTIONNAIRE ON NATIONAL MASS-MOUMENT SITE INVESTIGATION & MONITORING

SafeLand

Study site:

GENERAL INFORMATION:

Country:	<input type="text"/>															
Location:	<input type="text"/> WGS coordinates: <input type="text"/> , <input type="text"/>															
Responsible institutions:	<input type="text"/>															
Email contacts:	<input type="text"/>															
Date of the answering:	<input type="text"/>															
Type of slope failure: (modified classification of Cruden & Varnes 1996) <table border="0"> <tr> <td><input type="checkbox"/> Topple and initial fall:</td> <td>in rock <input type="checkbox"/></td> <td>in soil <input type="checkbox"/></td> </tr> <tr> <td><input type="checkbox"/> Lateral spread:</td> <td>in rock <input type="checkbox"/></td> <td>in soil <input type="checkbox"/></td> </tr> <tr> <td><input type="checkbox"/> Slide - translational:</td> <td>in rock <input type="checkbox"/></td> <td>in soil <input type="checkbox"/></td> </tr> <tr> <td><input type="checkbox"/> Slide - rotational:</td> <td>in rock <input type="checkbox"/></td> <td>in soil <input type="checkbox"/></td> </tr> <tr> <td><input type="checkbox"/> Flow:</td> <td>in rock <input type="checkbox"/></td> <td>in soil <input type="checkbox"/></td> </tr> </table>		<input type="checkbox"/> Topple and initial fall:	in rock <input type="checkbox"/>	in soil <input type="checkbox"/>	<input type="checkbox"/> Lateral spread:	in rock <input type="checkbox"/>	in soil <input type="checkbox"/>	<input type="checkbox"/> Slide - translational:	in rock <input type="checkbox"/>	in soil <input type="checkbox"/>	<input type="checkbox"/> Slide - rotational:	in rock <input type="checkbox"/>	in soil <input type="checkbox"/>	<input type="checkbox"/> Flow:	in rock <input type="checkbox"/>	in soil <input type="checkbox"/>
<input type="checkbox"/> Topple and initial fall:	in rock <input type="checkbox"/>	in soil <input type="checkbox"/>														
<input type="checkbox"/> Lateral spread:	in rock <input type="checkbox"/>	in soil <input type="checkbox"/>														
<input type="checkbox"/> Slide - translational:	in rock <input type="checkbox"/>	in soil <input type="checkbox"/>														
<input type="checkbox"/> Slide - rotational:	in rock <input type="checkbox"/>	in soil <input type="checkbox"/>														
<input type="checkbox"/> Flow:	in rock <input type="checkbox"/>	in soil <input type="checkbox"/>														
Complex failure: <input type="checkbox"/> Other: <input type="checkbox"/> Deep-seated gravitational deformation (initial stage of other deep-seated movement) <input type="checkbox"/>																
Present maximum movement rates (within past 12 months) <input type="checkbox"/> < 10 mm/month <input type="checkbox"/> < 10 cm/month <input type="checkbox"/> < 100 cm/month <input type="checkbox"/> > 100 cm/month Maximum expected future rate: <input type="text"/>	Present activity state (within past 12 months) <input type="checkbox"/> Active <input type="checkbox"/> Suspended <input type="checkbox"/> Reactivated <input type="checkbox"/> Dormant <input type="checkbox"/> Stabilized <input type="checkbox"/> Relict															
Maximum estimated thickness: <input type="text"/> m	Estimated volume: <input type="text"/> m ³															

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QUESTIONNAIRE ON NATIONAL MASS-MOUMENT SITE INVESTIGATION & MONITORING

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AVAILABLE INVESTIGATION:

Mapping: <input type="checkbox"/> Geological (lithology, stratigraphy, joint and fault pattern) <input type="checkbox"/> Geomorphic (topography, geomorphic features, etc.) <input type="checkbox"/> Engineering-geological (landslide regions, strength properties, vectors of movement, infrastructure, etc.) <input type="checkbox"/> Hazard, risk, element at risk, etc. <input type="checkbox"/> Hydrogeological (drainage network, underground drainage, aquifers, etc.) Other: <input type="text"/> Other: <input type="text"/>		
Drilling: <input type="checkbox"/> Core <input type="checkbox"/> Other: <input type="text"/> Max. depth: <input type="text"/> m		
Testing: <input type="checkbox"/> Strength properties/ deformability <input type="checkbox"/> Clay mineralogy <input type="checkbox"/> Penetration <input type="checkbox"/> Hydrochemical tracing <input type="checkbox"/> Hyperspectral satellite data <input type="checkbox"/> Field dilatation tests (pressuremeter) <input type="checkbox"/> Borehole testing Please specify: <input type="text"/> Other: <input type="text"/> Other: <input type="text"/>	Technique assessment Effectiveness / Reliability of the method for landslide investigation High Low	
Remote sensing data: <input type="checkbox"/> Aerial photographs and orthophotographs <input type="checkbox"/> Satellite optical very high resolution (VHR) imagery (< 2m pixel) <input type="checkbox"/> Hyperspectral satellite data <input type="checkbox"/> Airborne Geophysics <input type="checkbox"/> LIDAR ALS (Airborne Laser Scanning) <input type="checkbox"/> Radar Interferometry Other: <input type="text"/> Other: <input type="text"/>	High Low	
GB Geophysical survey: <input type="checkbox"/> Resistivity <input type="checkbox"/> Self potential (SP) <input type="checkbox"/> Induced polarization (IP) <input type="checkbox"/> Reflection seismic <input type="checkbox"/> Refraction seismic <input type="checkbox"/> Ground Penetrating Radar (GPR) <input type="checkbox"/> Frequency-domain electromagnetics <input type="checkbox"/> Time-domain electromagnetics <input type="checkbox"/> Proton (nuclear) magn. resonance (PMR) <input type="checkbox"/> Hydrophysical logging in boreholes Other: <input type="text"/> Other: <input type="text"/>	High Low	

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QUESTIONNAIRE ON NATIONAL MASS-MOUMENT SITE INVESTIGATION & MONITORING

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MONITORING OF MOVEMENT AND DEFORMATION:

Remotely sensed: <input type="checkbox"/> Satellite optical VHR image (type: <input type="text"/>) Duration: <input type="text"/> years Number of scenes: <input type="text"/> <input type="checkbox"/> Satellite near infrared image (type: <input type="text"/>) Duration: <input type="text"/> years Number of scenes: <input type="text"/> <input type="checkbox"/> Orthophoto Duration: <input type="text"/> years Number of scenes: <input type="text"/> <input type="checkbox"/> InSAR (Radar Interferometry) Duration: <input type="text"/> years Number of scenes: <input type="text"/> <input type="checkbox"/> LIDAR ALS (Airborne Laser Scanning) Duration: <input type="text"/> years Number of scenes: <input type="text"/> Other: <input type="text"/> Duration: <input type="text"/> years Number of scenes: <input type="text"/>	Active? Duration Permanent X Regular X Sporadic Potential for EW?			
Ground based: <input type="checkbox"/> GB InSAR (Radar Interferometry) <input type="checkbox"/> LIDAR TLS (Terrestrial Laser Scanning) <input type="checkbox"/> Optical image <input type="checkbox"/> Near infrared image <input type="checkbox"/> dGPS (Global Positioning System) <input type="checkbox"/> Total station <input type="checkbox"/> Inclinomometer (classical) <input type="checkbox"/> Automatic inclinometer (DMS, etc.) <input type="checkbox"/> Tape extensometers <input type="checkbox"/> Wire extensometers (automatic) <input type="checkbox"/> TM 71 (opto-mechanical extensometer) <input type="checkbox"/> Optical Fibres (FOC) Other: <input type="text"/> Other: <input type="text"/> Other: <input type="text"/>	Active? Duration Permanent X Regular X Sporadic Potential for EW?			

Explanation:
 Active: Is the monitoring still in use? (tick = yes)
 Duration: Please write duration of monitoring (in years)
 Permanent: Is the monitoring (usually automatic) continuous and regular with periodicity shorter than 1 week?
 Regular: Is the monitoring continuous with regular periodicity > 1 week and < 1 year?
 Sporadic: Is the monitoring with periodicity irregular: on > 1 year?
 Potential for EW: Could be the monitoring technique used for Early Warning?

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QUESTIONNAIRE ON NATIONAL MASS-MOUMENT SITE INVESTIGATION & MONITORING

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MONITORING OF FACTORS:

Hydro-meteorological: Precipitation amount Snow cover thickness Solar radiation Air temperature Air humidity Pore-water pressure Soil temperature Soil humidity Water temperature Fluid conductivity In / outflow (discharge) Other: <input type="text"/> Other: <input type="text"/> Other: <input type="text"/>	Active? Duration Permanent X Regular X Sporadic Potential for EW?			
Geophysical: Passive seism./acoustic emission Electromagnetic emissions Self potential (SP) Induced polarization (IP) DC (Direct Current) resistivity Other: <input type="text"/> Other: <input type="text"/>	Active? Duration Permanent X Regular X Sporadic Potential for EW?			

NUMERICAL MODELING:

Method 1: <input type="text"/>	Code name: <input type="text"/>	Studied behavior: <input type="text"/>
Method 2: <input type="text"/>	Code name: <input type="text"/>	Studied behavior: <input type="text"/>
Method 3: <input type="text"/>	Code name: <input type="text"/>	Studied behavior: <input type="text"/>

RELEVANT PUBLICATIONS AND REPORTS:

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Fig. 1: General appearance of the Questionnaire on National State of Landslide Site Investigation and Monitoring.

Table 1: Review of the number of sites and countries included in the study.

No.	Country Code	Country	Number of Sites
1	AD	Andorra	1
2	AT	Austria	7
3	CH	Switzerland	3
4	CZ	Czech Republic	11
5	ES	Spain	1
6	FR	France	5
7	GB	Great Britain	1
8	IT	Italy	22
9	KG	Kyrgyzstan	8
10	NO	Norway	3
11	RU	Russia	1
12	SI	Slovenia	3
13	SK	Slovakia	16



Fig. 2: Reviewing map of countries included in the study (source of map: GoogleEarth).

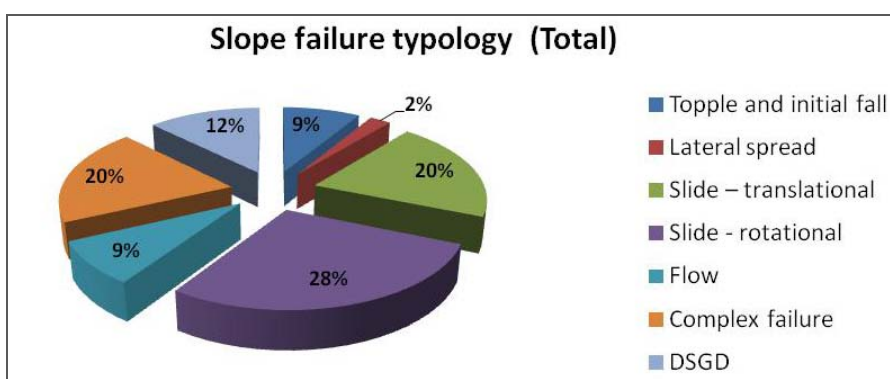


Fig. 3: Review of monitored slope failures included in the study (modified classification of CRUDEN & VARNES, 1996).

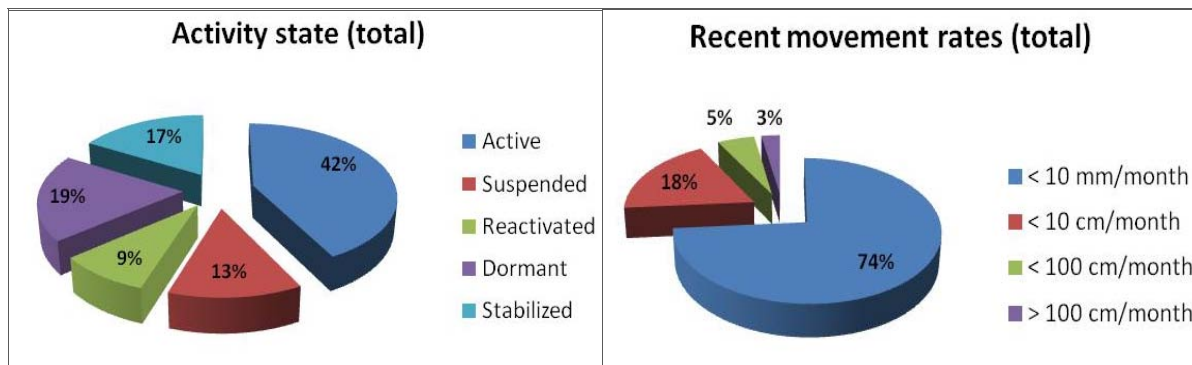


Fig. 4: Review of slope failures included in the study by their activity state (after WP / WLI, 1993) and actual movement rates.

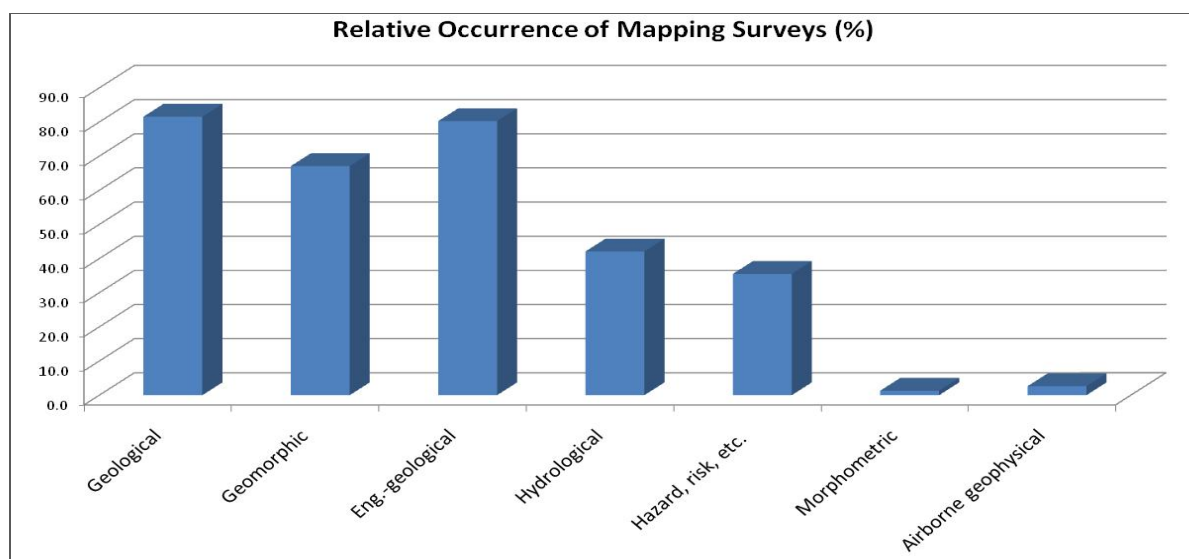


Fig. 5: Review of relative occurrence of different mapping approaches (per number of sites) applied in the case sites.

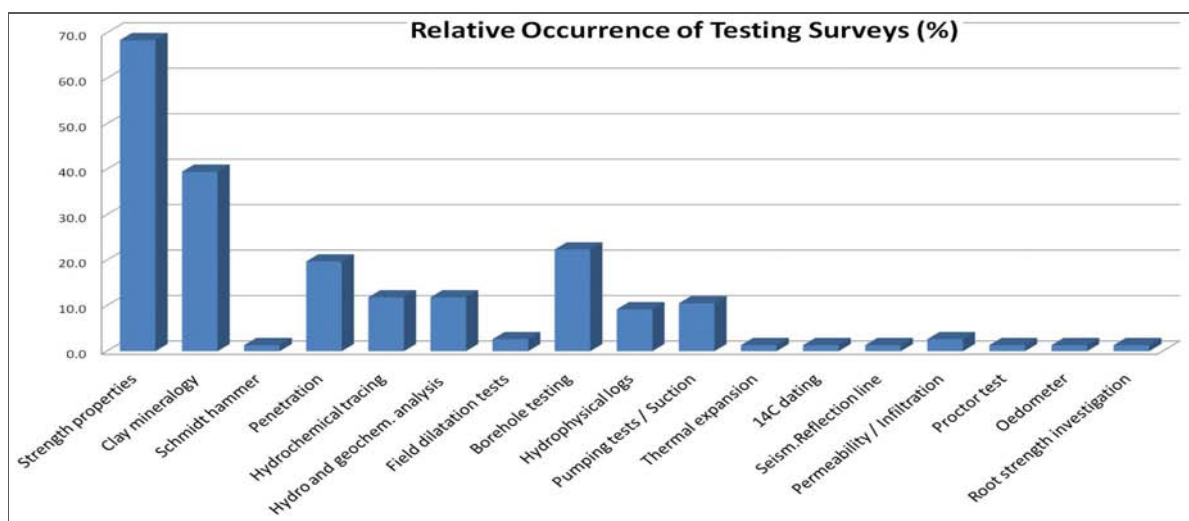


Fig. 6: Review of relative occurrence of different testing approaches applied in the case sites.

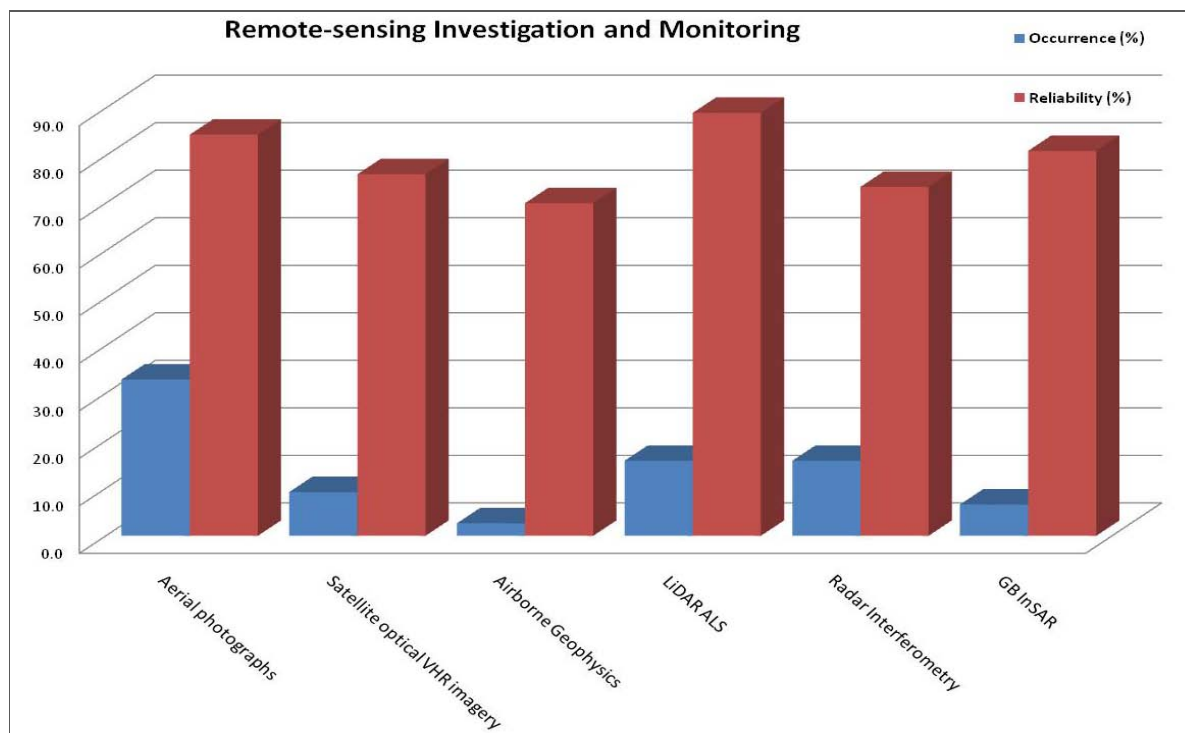


Fig. 7: Review of relative occurrence (blue) and relative reliability (red) of different remote-sensing data applied for investigating or monitoring of the case sites.

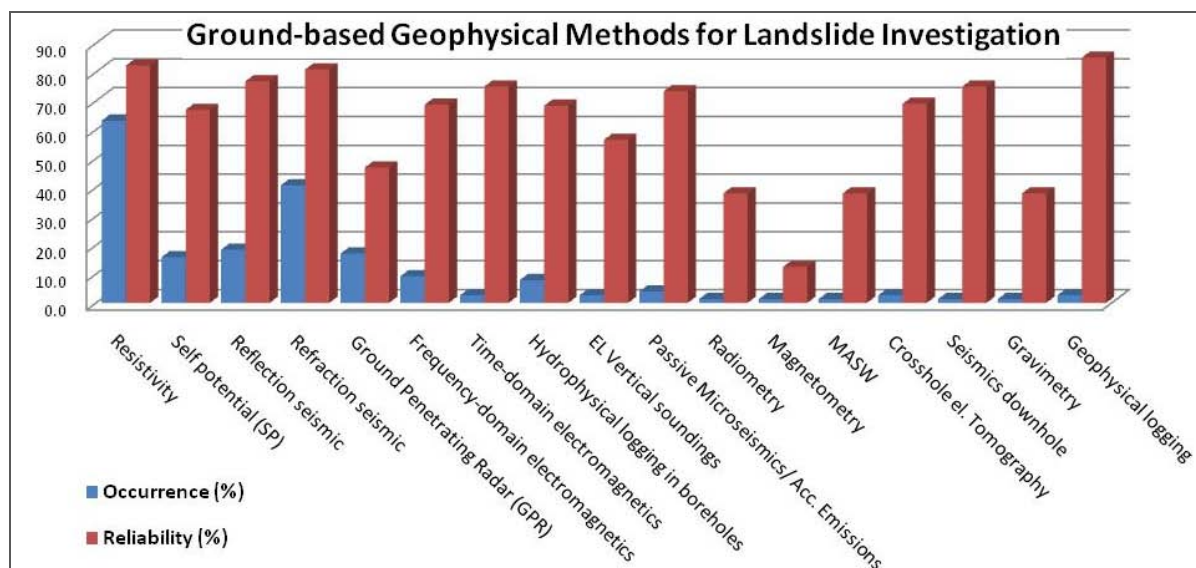


Fig. 8: Review of relative occurrence and reliability of different geophysical methods applied for investigation of the case sites.

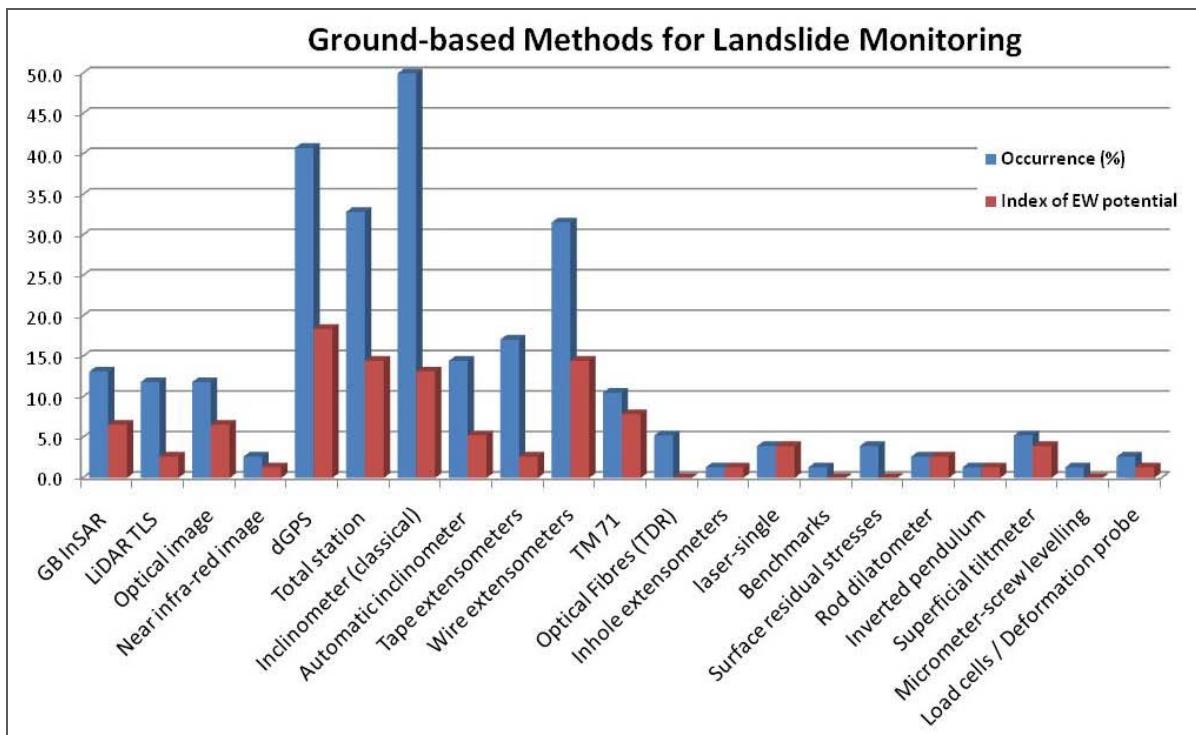


Fig. 9: Review of relative occurrence and index of early-warning potential of ground-based techniques applied for displacement and deformation monitoring of the case sites.

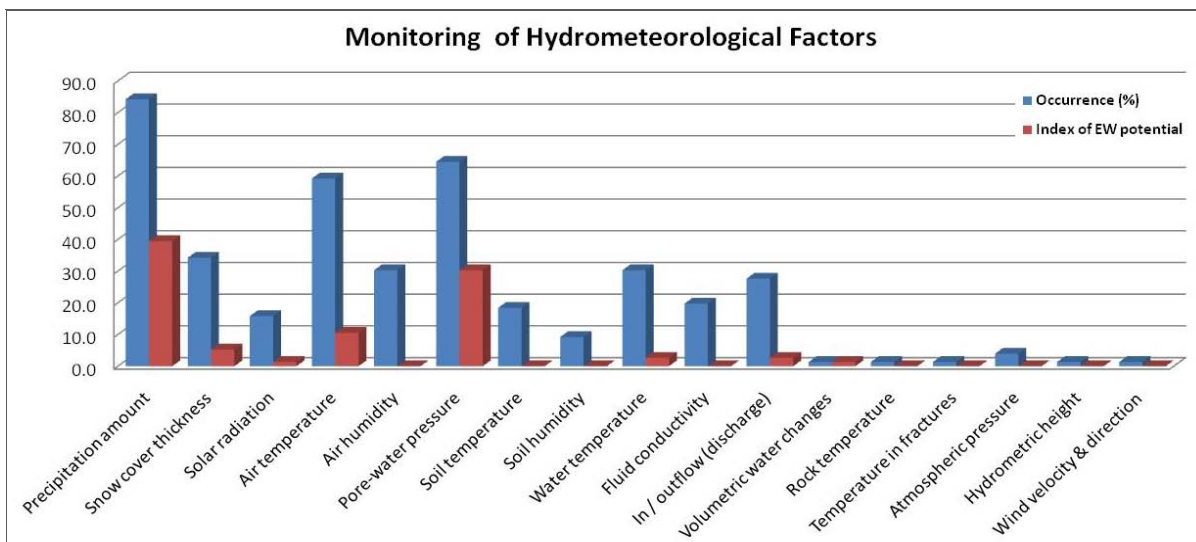


Fig. 10: Review of monitoring of hydrometeorological factors at the case sites, and their index of early-warning potential.

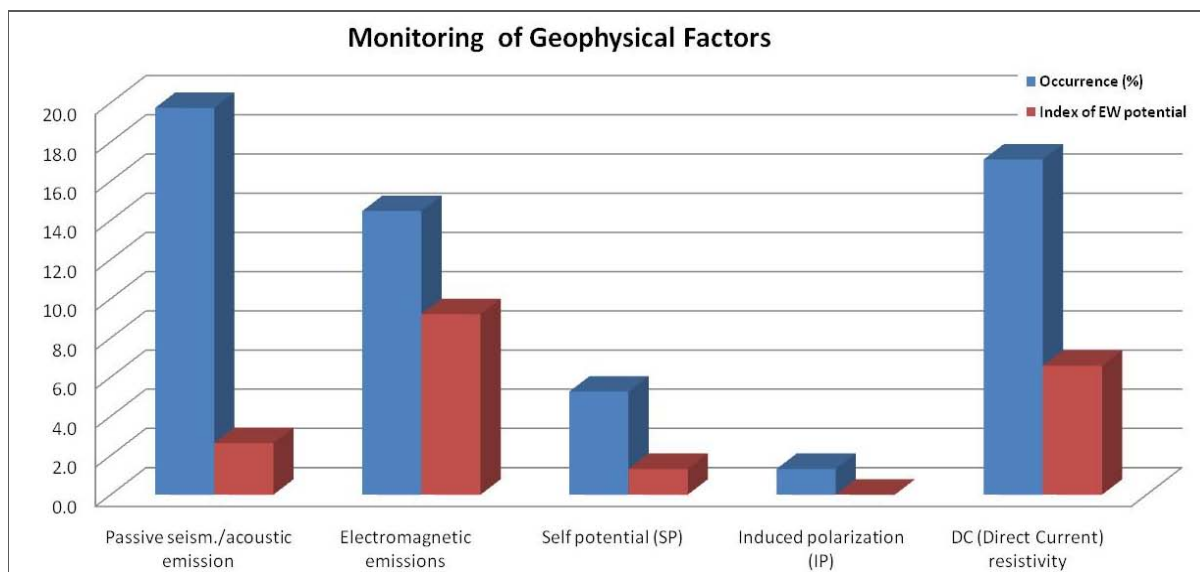


Fig. 11: Review of monitoring of geophysical factors at the case sites, and their index of early-warning potential.

Acknowledgement

The authors would like to **acknowledge everyone who helped through discussions to improve the form** to be as comprehensive and "user-friendly" as possible. Special thanks go to all the local national coordinators who helped to disseminate the questionnaire effectively and to obtain as many answers as possible; and, of course all specialist and responsible persons, who filled in the form, must be thanked, i.e.: **M. Bil, P. Blaha, J. Blanc, L.H. Blikra, M. Broccolato, S. Cardellini, M. Carman N. Casagli, J. Corominas, C. Foster, S. Garambois, W. Gasperl, V. Hanzl, F. Hartvich, A. Helmstetter, Ch. Ihrenberger, M.M. Ilyin, D. Jongmans, V. Kaufmann, J. Klimes, S. Kumelj, M. Lovisolo, J.-F. Malet, S. Novosad, A. Passuto, L. Picarelli, J. Rybar, S. Springman, I. Torgoev, G. Truffelli, G. Urciuoli, Z. Varilova, P. Wagner, and M. Wöhrer-Alge.**

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References

CRUDEN, D.M. & VARNES, D.J. (1996): Landslide types and processes. In: Landslides, Investigation and Mitigation. Special Report 247, Transportation Research Board, Washington, 36–75.