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

I. BAROŇ & R. SUPPER

Geological Survey of Austria, Neulinggasse 38, 1030 Vienna, Austria.

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.

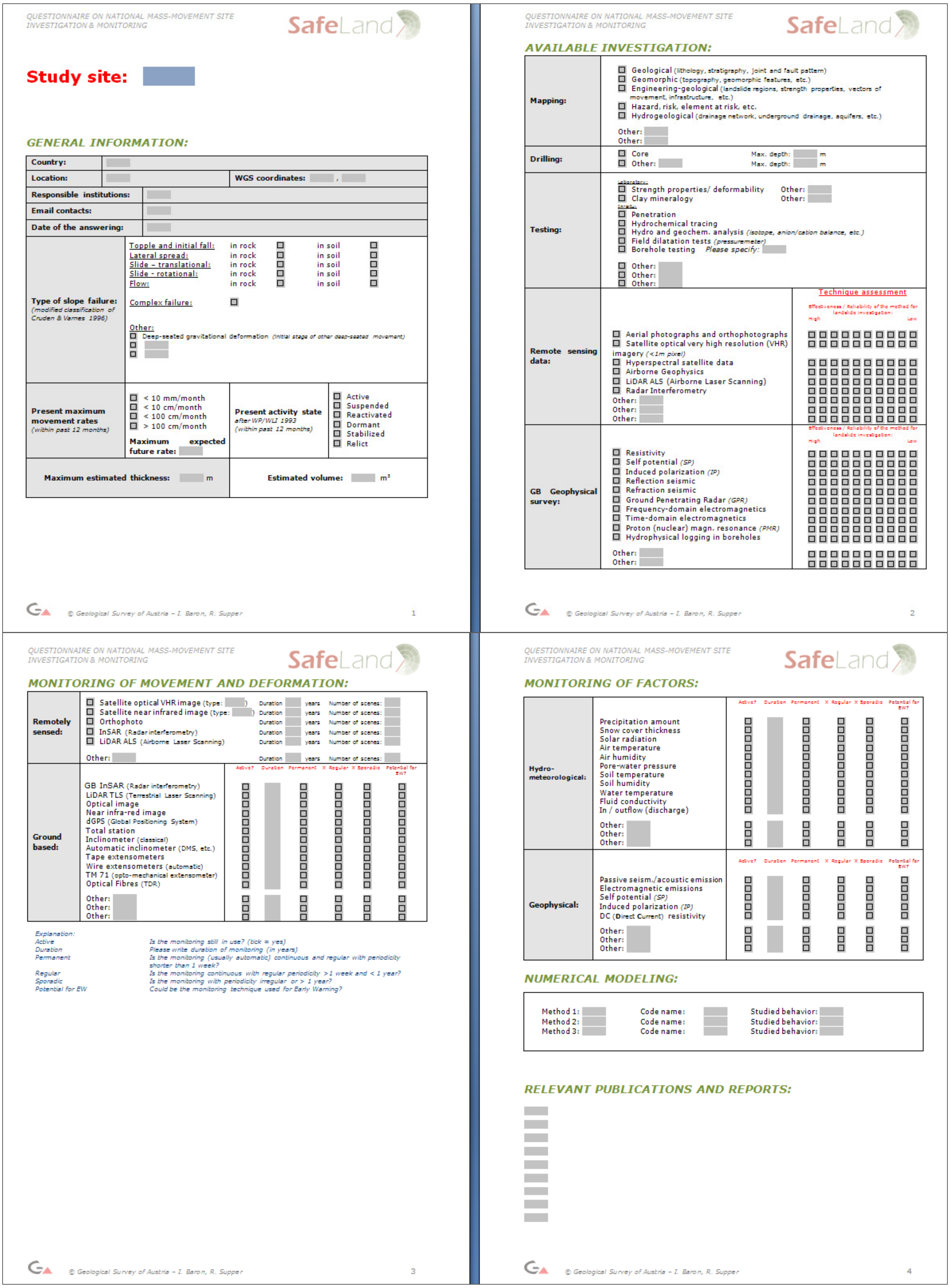

Fig. 1: General appearance of the Questionnaire on National State of Landslide Site Investigation and Monitoring.

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).

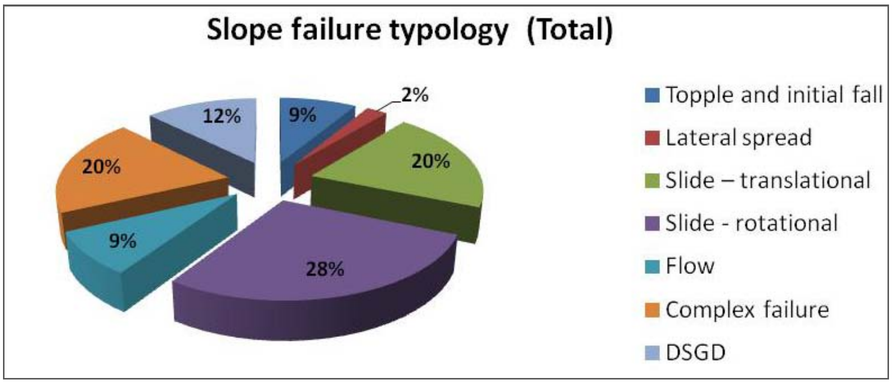

Fig. 3: Review of monitored slope failures included in the study (modified classification of CRUDEN & VARNES, 1996).

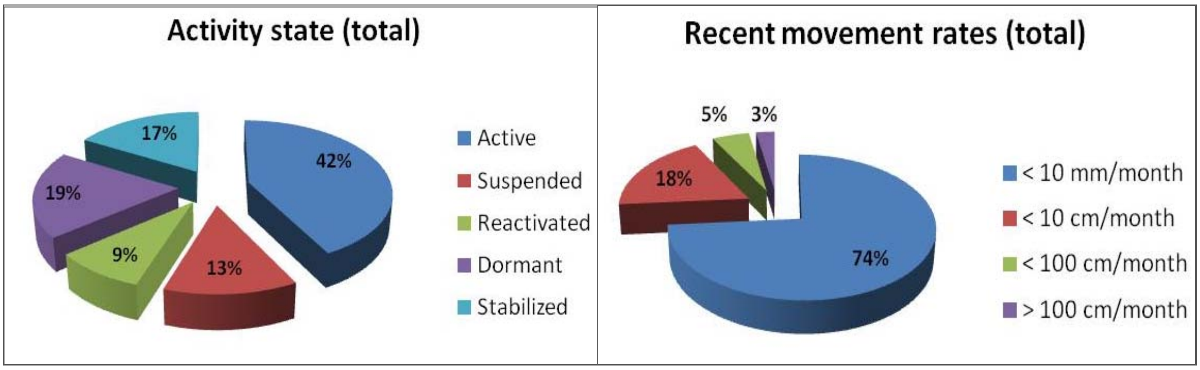

Fig. 4: Review of slope failures included in the study by their activity state (after WP / WLI, 1993) and actual movement rates.

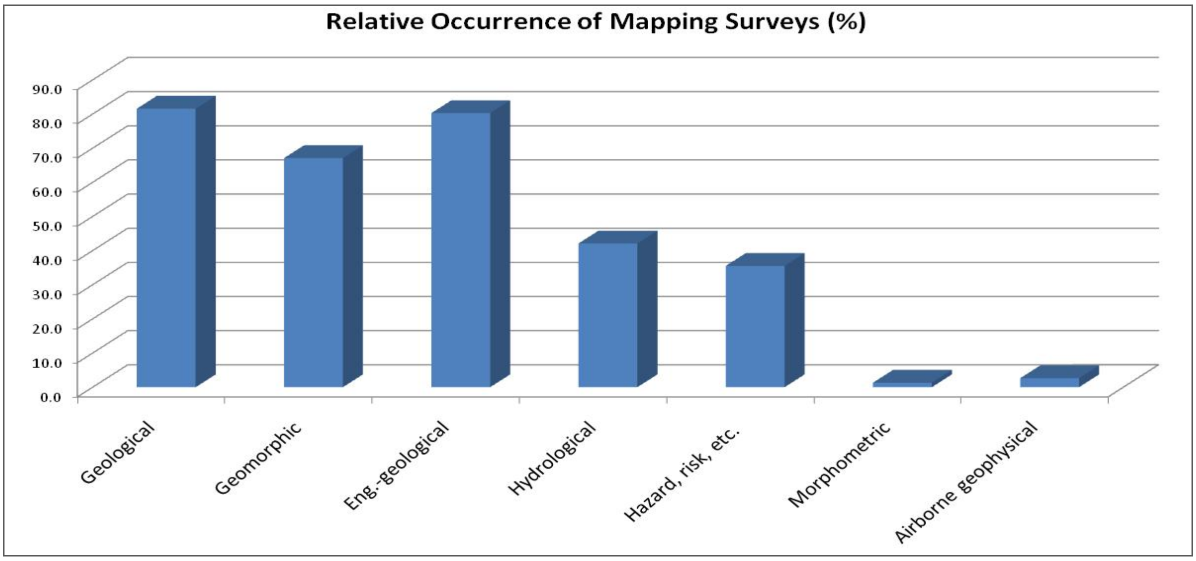

Fig. 5: Review of relative occurrence of different mapping approaches (per number of sites) applied in the case sites.

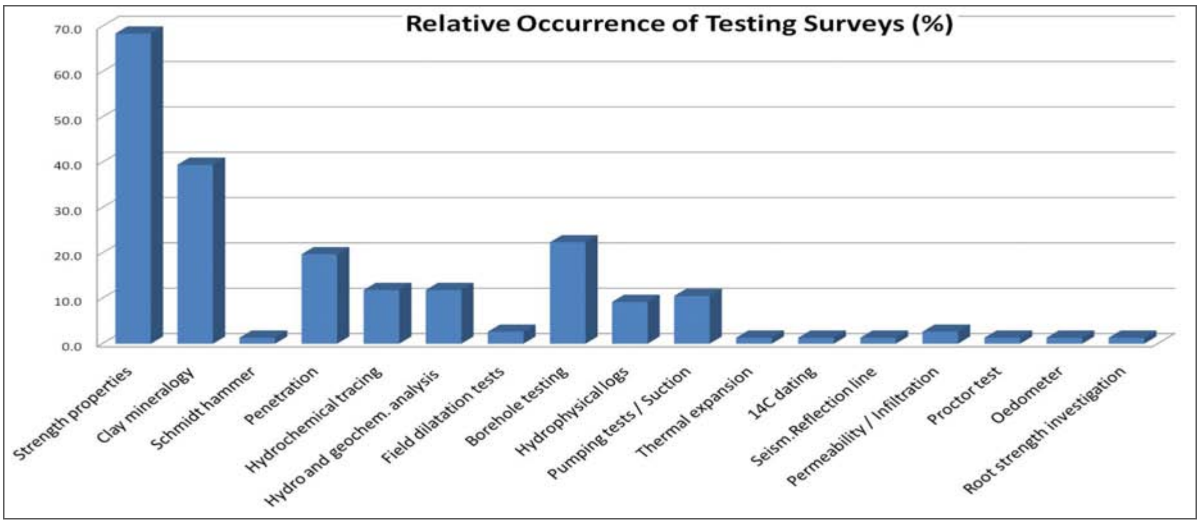

Fig. 6: Review of relative occurrence of different testing approaches applied in the case sites.

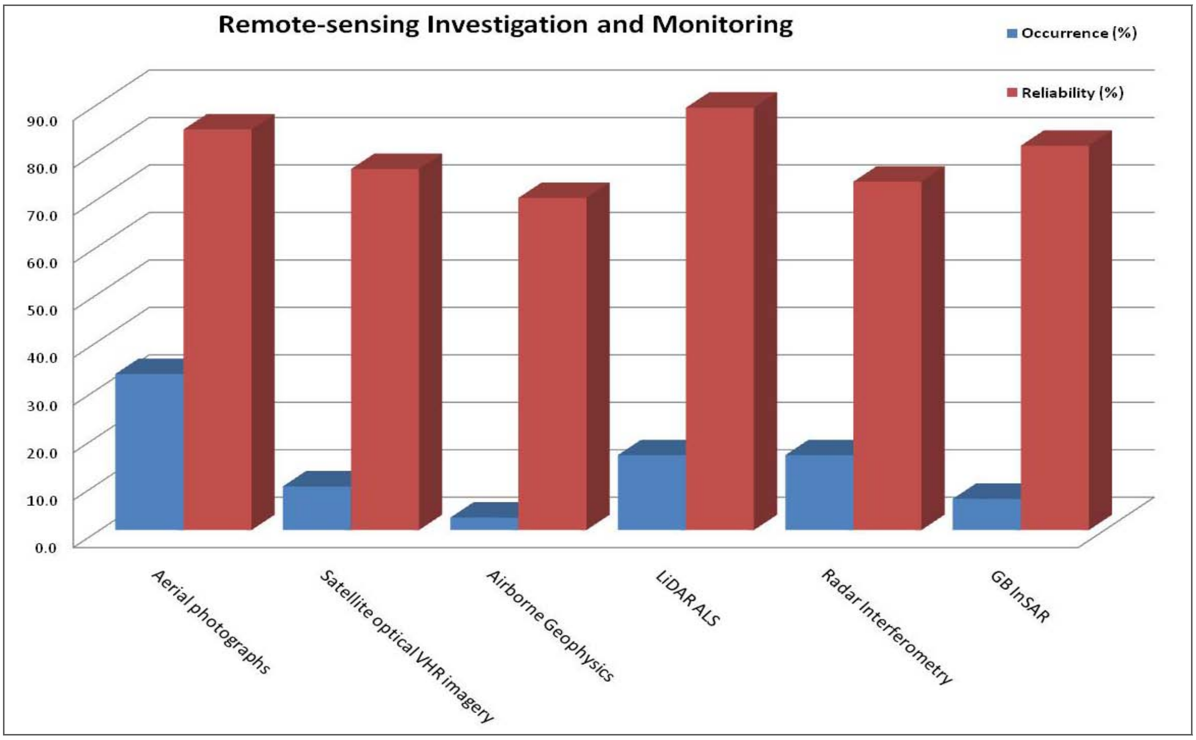

Fig. 7: Review of relative occurrence (blue) and relative reliability (red) of different remote-sensing data applied for investigating or monitoring of the case sites.

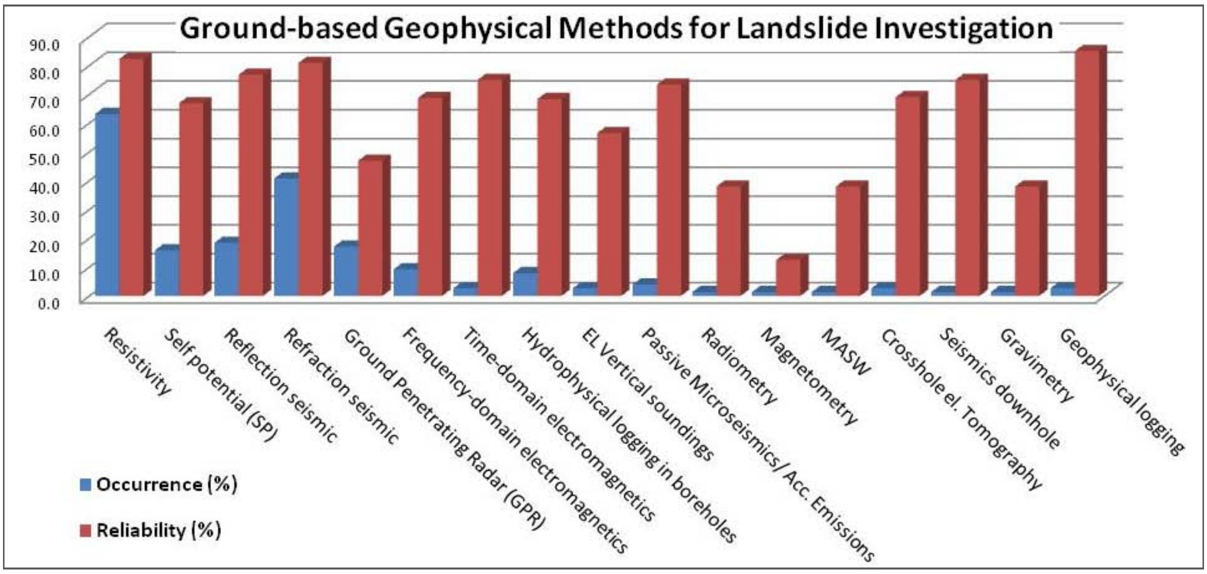

Fig. 8: Review of relative occurrence and reliability of different geophysical methods applied for investigation of the case sites.

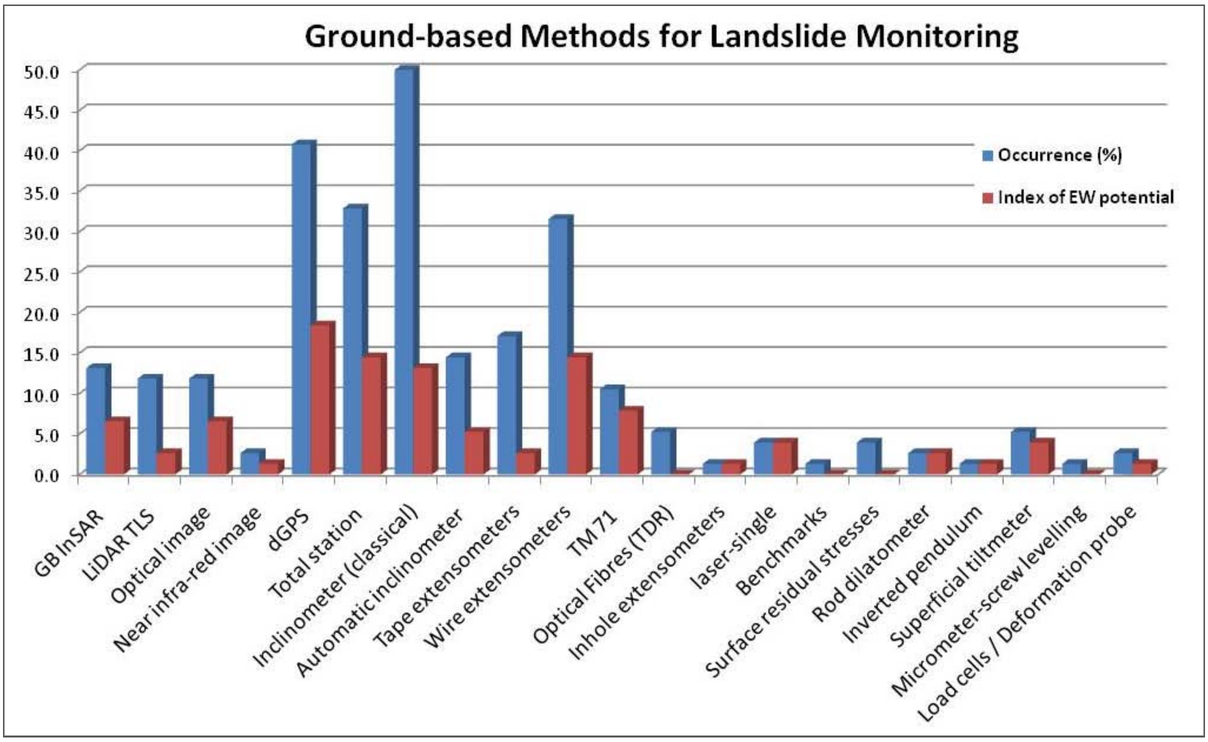

Fig. 9: Review of relative occurrence and index of early-warning potential of ground-based techniques applied for displacement and deformation monitoring of the case sites.

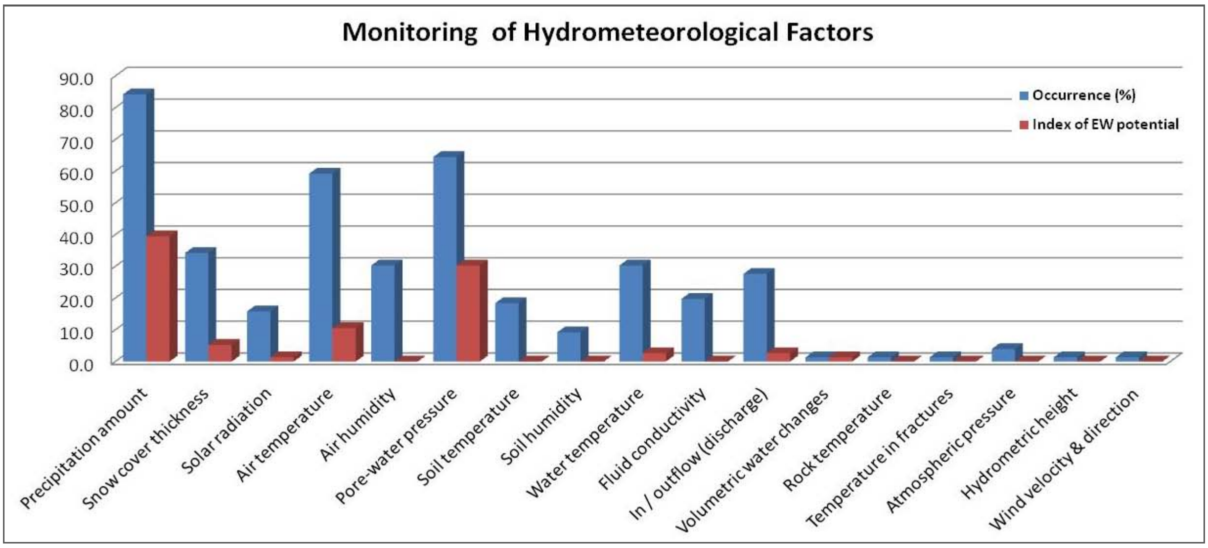

Fig. 10: Review of monitoring of hydrometeorological factors at the case sites, and their index of early-warning potential.

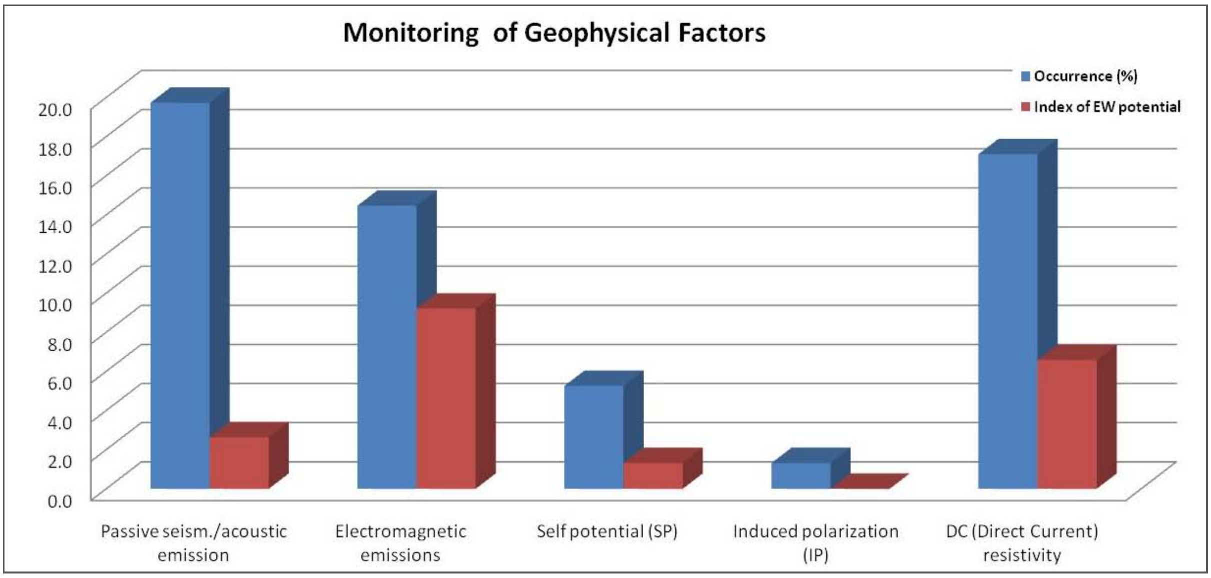

Fig. 11: Review of monitoring of geophysical factors at the case sites, and their index of early-warning potential.

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References

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