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Landslide monitoring for warning purposes: comparison of systems operating at slope scale

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Monitoring is a crucial activity of Landslide Early Warning Systems (LEWS). Typical components of landslide monitoring networks include field sensors, data acquisition systems, remote telemetry, and software for data processing and dissemination. Monitoring to be used within an operational LEWS is, necessarily, long-term monitoring. By elaborating on experiences presented in the literature, the landslide monitoring instruments are herein classified in terms of monitored parameters and monitoring methods. The parameter to be monitored are grouped in four categories: deformation activity, groundwater, trigger and predisposing factor. The monitoring methods are classified in six categories: geotechnical, hydrologic, geophysical, geodetic, remote sensing, meteorological. Two categories of LEWSs can be defined on the basis of the scale of operation and considering the landslide's typology: local LEWSs, when they deal with a single landslide system at slope scale; and territorial LEWSs, if they deal with multiple landslides at regional scale, i.e. over a basin, a municipality, a region or a nation. A review, carried out by the Authors on local LEWSs (Lo-LEWSs) for which information is reported in the scientific and/or grey literature, comprised a great variety of slope instabilities, including: debris flows, rockslides, rock avalanches, deep seated colluvial landslides, rainfall-induced landslides, cliff top recessions, rockfalls and mudslides. By comparing the different monitoring strategies developed within the 28 Lo-LEWSs reviewed, interesting practical trends can be derived. The monitoring methods are strictly correlated to the site-specific conditions of the slope to be monitored and, as a consequence, to the parameters to be investigated. In particular, the technicians area asked to identify suitable parameters related to landslide triggering conditions, and then select the most appropriate monitoring instruments according to a set of criteria, such as: simplicity, robustness, reliability and cost. Geotechnical and meteorological methods are the most employed among the systems reviewed, since they are considered in 20 cases out of 28. The large majority of the systems (26) is based on the monitoring of the deformation, mainly in terms of displacement (15), velocity (8) and acoustic signal (7). This is certainly due to the fact that they show direct evidence of active deformations and, as a consequence, movements in the slope. A large number of Lo-LEWSs also monitor triggering parameters (23 cases out of 28), particularly weather data since rainfall and snowmelt have been considered as triggering factors in 21 systems. Finally, it is important to highlight that redundancy is a crucial aspect for developing monitoring strategies. This is confirmed by the large number of Lo-LEWSs employing more than one monitoring method.