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Review on deep-seated landslides in the Carpathians under climate variability/change and their implication in hazard assessment

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In mountain regions, landslides are enhancing the short- to long-term slope denudation and sediment delivery, conditioning the general landscape evolution; meanwhile, their regional typological patterns should be properly incorporated into single- to multi-hazard evaluations for a proper mitigation of consequences and risk management strategies development. The Carpathians are an elongate and twisted young mountainous chain of Europe, which is continuing the Alpine orogenetic system towards the internal, Central and Eastern parts of the continent, covering parts of Austria, Czech Republic, Slovakia, Poland, Ukraine, Romania and Serbia. Their heterogeneous morphological and litho-structural forming conditions, the regional climatic traits and the extremely complex and complicated political and socio-economical development stages resulted in a landslide-prone environment, as outlined through numerous scientific works. Nevertheless, there is little synthesis information which can allow a clear evaluation of the entire mountain chain, highlighting the importance of such a study in the present-day context of climate variability and change analysis. As part of the broad landslide typological spectrum, the deep-seated landslides are important paleo-environmental witnesses which may offer substantial information within the risk management and resilience construction context under the modern challenges of climate change impact evaluation. The complexity (many times site-specific) of deep-seated landslides susceptibility and hazard evaluation is enhanced by the (very) high magnitude of such processes, marking with a substantial share the evolution of the coupled slope and channel morphodynamic systems, an interface usually prone to the development of human activities, thus driving the fundamental understanding of their morphogenesis towards highly applied exposure analysis, vulnerability evaluations and risk mitigation concerns. In order to obtain a full extent evaluation of the implication of deep-seated landslides in hazard assessment, a consistent literature review was performed. Several key-issues in understanding the complexity of hazard evaluation, from inventory to susceptibility and frequency/magnitude or triggering thresholds and their return periods were studied: predisposition traits (structure, lithology, terrain/elevation models), preparing conditions (neotectonics, seismicity, human influence, climate variability), triggering factors (precipitation and climate change, earthquakes, anthropic activities), landslide

inventories (graphic representations and spatio-temporal coverage), susceptibility modelling (in terms of methods, purpose, units, validation methods, existence of sensitivity analysis), triggering thresholds (scale, typologically-adapted or not, theoretical/validated, recurrences, EWS or forecast systems) and hazard evaluation (scale, typologically-adapted or not, theoretical/validated, expressed in terms of susceptibility, relative hazard or hazard). The purpose of this paper is to harmonize for the first time at the entire mountain chain's continental scale the information concerning the role of deep-seated landslides inside the complex hazard assessment framework. A special attention is directed towards climate variability/change related implications, since the Carpathians, through their more internal, continental position, are representing a key environment for the assessment of continental climate change adaptation strategies.