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Geomorphological characteristics of landslides in the Hrvatsko Zagorje (NW Croatia)

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A landslide inventory presents a detailed register of the distribution and characteristics of past landslides in a specific area. Landslide inventory maps and other maps such as landslide susceptibility, hazard and risk maps present an essential tool in landslide risk management, supporting authorities, practitioners and decision-makers in the more appropriate and sustainable land planning and risk mitigation strategy development. In recent years, Light Detection and Ranging (LiDAR) data have been commonly used to map landslide morphology and estimate landslide activity. LiDAR is a consolidated remote sensing technique used to obtain digital representations of the topographic surface for areas ranging from a few hectares to thousands of square kilometres. From elevation point clouds obtained by laser scanning, a detailed digital elevation model (DEM) and different DEM derivatives, such as slope, hillshade or contour maps, can be produced. In this study, a historical landslide inventory map of the Hrvatsko Zagorje area (NW Croatia), interpreted from LiDAR high-resolution DEM (HRDEM) derivates, is presented and analyzed regarding geomorphological characteristics. The study area comprises 20.22 km^2 of the hilly terrain (88% of the area has slope angles >5°), mostly covered by forests (52%). The area is composed of Triassic carbonate rocks, Miocene clastic sedimentary rocks and soils and Quaternary alluvial soils. LiDAR data for the study area was acquired in the framework of the project „Methodology development for landslide susceptibility assessment for land-use planning based on LiDAR technology (LandSlidePlan)" financed by the Croatian Science Foundation. The topographic derivative datasets used to interpret the landslide morphology were hillshade maps, slope maps and contour lines. Landslide identification on the LiDAR HRDEM derivatives (0.3 m resolution) was manual and GIS-assisted, based on recognizing landslide features (e.g., concave main scarps, hummocky landslide bodies and convex landslide toes). The mapping was performed at a large scale (1:100–1:500) to ensure the correct delineation of the landslide boundaries. Totally 912 landslides were mapped. The total area of mapped landslides is 0.408 km^2, or 2.02% of the study area, and the mean landslide density is 45.1 slope failures per square kilometre. The average landslide area is 448 m^2 (median□=□173 m^2). The small size of the landslides is probably the result of geological conditions (mainly Miocene marls covered with residual soils) and geomorphological conditions, where the differences between the valley bottoms and the top of the hills are rarely higher than 100 meters. Geomorphological characteristics of mapped landslides were compared with characteristics of the stable terrain using different DEM derivatives, such as roughness and curvature. According to the analyses, roughness and curvature values are distributed differently in landslides and stable terrain. Knowledge of the difference between the geomorphological characteristics of landladies and stable terrain provides valuable information for the automatic mapping of landslides and potently unstable slopes.