



Distribution and morphological characteristics of dolines in Slovenia defined by lidar data sets and machine learning

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Dolines are small and to intermediate enclosed karst depressions and are the most numerous karst feature in Slovenia. They are circular in plan form and vary in diameter from few metres to over a kilometre. They developed on limestone, dolomite and conglomerate and occupy different geomorphic settings. They were formed by various processes like dissolution, collapse, suffosion and transformation of caves to surface forms by denudation. Abundance, variety and dimensions make study of doline difficult, so they were studied on a small areas only.

For this study we used data, provided by lidar scanning of whole Slovenia. To catalog dolines we manually label a fraction of digital elevation model of Slovenia with a binary mask, indicating if territory is a doline or not. We then train slightly modified Unet, a type of machine learning algorithm (<https://arxiv.org/abs/1505.04597>) on the labelled territory. Using the trained algorithm we infer the binary mask on the entire DEM of Slovenia. We convert the resulting mask into ESRI Shapefile and manually verify the results. We note that the training and inference is error prone on types of relief that were less common in the training set (e.g. the relatively uncommon collapse dolines). We believe manual verification mitigates most of these errors, so the resulting map is a good basis for the doline study.

Dolines occupy most of 7400 km² of karst areas except mountains where were destroyed by glaciers or covered by glacial till. We marked 471,192 dolines and divided them to three genetic types. Most abundant (470,325) are solution dolines. Average dolina is 9 m deep, has a diameter of 42 m and volume of 14,098 m³. Density of dolines on levelled surfaces can be higher than 400 per km². They are missing on bottoms of poljes and on steeper slopes and are less abundant on inclined surfaces.

Collapse dolines are formed by locally enhanced dissolution of limestone due to specific type of fracturisation of rock and underground rivers or flow. routes where large oscillations of ground water occur. We have designated 314 dolines to be of collapse origin. Mean depth of collapse dolines is 49 m, and 20 of them is deeper than 100 m. Mean volume is 1.2 Mm³, with the largest having volume 11.6 Mm³. Most of collapse dolines can be found close to ponors or springs or corridors where large underground rivers flow.

Alluvial dolines are formed by suffosion of sediments deposited on karst surface to underground forming funnel like depressions. As the sediments are mostly deposited in blind valleys or on poljes most of these 553 features are located in such environments.

This basic data set for dolines enables further study and comparison of dolines with geology and topography of the karst.