Mapping cliff face changes around a waterfall using terrestrial laser scanning and UAS-based SfM-MVS photogrammetry

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Abstract. Waterfall is often the front of fluvial erosion into bedrock in mountainous and plateau areas. Following the rapid erosion of waterfall, rockfalls and gravitational collapses often occur in surrounding steep cliffs due mainly to weathering of the bedrock exposed. Although morphological changes of such steep cliffs are often visually observed, quantitative measurements of their spatiotemporal distribution have been limited. Mapping of the morphological changes is therefore crucial to clarify the processes occurring in the cliffs and to prevent related slope disasters. Here we perform multi-temporal terrestrial laser scanning (TLS), as well as structure-from-motion multi-view stereo (SfM-MVS) photogrammetry based on small unmanned aerial vehicle (sUAV), to achieve accurate mapping of such morphological changes. The study site is Kegon Falls in central Japan, having a vertical drop of surface water from the top of its cliff and groundwater outflows from its lower portion. The entire cliff is mostly overhanging and minor rockfalls are often observed by local people. The latest major rockfall occurred in 1986, causing an approximate 8-m upstream shift (recession) of the waterfall lip. This provides a good opportunity to examine the changes in the surrounding cliffs following the waterfall recession. From the multi-time point clouds obtained by TLS measurement, the three-dimensional changes of the cliff surface, i.e., the locus of small rockfalls, gully develop-ments and vegetation removal, are highlighted. Also, shadows in the TLS point clouds are effectively filled by complementary data of UAV-based SfM-MVS photogrammetry, improving the mapping quality of the cliff morphology and surrounding areas. The point clouds are also projected on a vertical plane to generate a digital elevation model (DEM). Cross-sectional profiles extracted from the DEM show the presence of a distinct, 5–10-m depression at the bottom of the upper andesite layer of the cliff, which appears to have been formed by

freeze–thaw and wet–dry weather-ing following the waterfall recession in 1986.

Keywords. waterfall, cliff, TLS, SfM-MVS, sUAV, point cloud, DEM