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Detection of morphological changes in cliff face surrounding a waterfall using terrestrial laser scanning and unmanned aerial system

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Waterfall or bedrock knickpoint appears as an erosional front in bedrock rivers forming deep v-shaped valley downstream. Following the rapid fluvial erosion of waterfall, rockfalls and gravita-tional collapses often occur in surrounding steep cliffs. Although morphological changes of such steep cliffs are sometimes visually observed, quantitative and precise measurements of their spatio-temporal distribution have been limited due to the difficulties in direct access to such cliffs if with classical measurement methods. However, for the clarification of geomorphological processes oc-curring in the cliffs, multi-temporal mapping of the cliff face at a high resolution is necessary. Re-mote sensing approaches are therefore suitable for the topographic measurements and detection of changes in such inaccessible cliffs. To achieve accurate topographic mapping of cliffs around a wa-terfall, here we perform multi-temporal terrestrial laser scanning (TLS), as well as structure-from-motion multi-view stereo (SfM-MVS) photogrammetry based on unmanned aerial system (UAS). The study site is Kegon Falls in central Japan, having a vertical drop of surface water from top of its overhanging cliff, as well as groundwater outflows from its lower portions. The bedrock is composed of alternate layers of andesite lava and conglomerates. Minor rockfalls in the cliffs are often ob-served by local people. The latest major rockfall occurred in 1986, causing ca. 8-m upstream propa-gation of the waterfall lip. This provides a good opportunity to examine the changes in the surround-ing cliffs following the waterfall recession. Multi-time point clouds were obtained by TLS measure-ment over years, and the three-dimensional changes of the rock surface were detected, uncovering the locus of small rockfalls and gully developments. Erosion seems particularly frequent in relatively weak the conglomerates layer, whereas small rockfalls seems to have occurred in the andesite layers. Also, shadows in the TLS point clouds are effectively filled by complementary data of UAS-based SfM-MVS photogrammetry, which can improve the mapping quality of the cliff morphology. 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 mid of the cliff (bottom of the upper andesite layer), which appears to have been formed by freeze–thaw and/or wet–dry weathering following the waterfall recession in 1986.